६०४०७३

CHAMBERS'S EDUCATIONAL COURSE.

ELECTRICITY

BY

ROBERT M. FERGUSON, PH.D. F.R.S.E.
OF THE EDINBURGH INSTITUTION.

WILLIAM AND ROBERT CHAMBERS
LONDON AND EDINBURGH
1868.

Edinburgh :
Printed by W. and R. Chambers

PREFACE.

The following work aims at giving a popular and accurate view of the main principles of the science of Electricity, and at preparing the way for the technical or mathematical study of them. It is intended to embrace the same class of readers as the *Chemistry* of the course, namely, the senior pupils at school, and junior students at college.

The work is divided into six sections; each section is divided into chapters; and each chapter into paragraphs. This division is made with a view to convey a clear idea of the connection of the main branches of the science, and of the various phenomena included under each. The fluid theories of electricity, on which the more usual terms of the science are based, are explained at sufficient length. They are apt, however, to convey the idea that electricity is a principle distinct from matter, an impression not borne out by experience. Throughout the work, electricity is looked upon as a peculiar action which the molecules of matter, under certain conditions, exert on each other. A method of explanation is adopted in keeping with Faraday's theory of induction, and the manifest action of induction, in which it is assumed that electric action is one of contiguous molecules, and that nothing but molecular action travels in a current; at the same time, each action is clearly described as it occurs, apart from theoretical considerations.

Care has been taken, as far as possible in an elementary work, to include the more recent inventions and methods. The British Association unit of resistance is adopted in the section on Galvanism, and a chapter is afterwards devoted to the method of determining it, and to the system of measurement of the current elements in electro-magnetic units. The French and German equivalent words are given where the same terms are not used. These equivalents frequently describe a piece of apparatus, or an electric action, from another point of view than that from which the English words are taken. Moreover, many of them, either in themselves or in their translations, have found their way into the English language, and they thus save the necessity of giving synonyms. A historical sketch is given at the end of each section or chapter, in which the author and the date of every important discovery or invention are carefully noted.

CONTENTS.

PAGE

INTRODUCTION ... vii

EXPLANATION OF ABBREVIATIONS ... ix

FRENCH MEASURES REFERRED TO, REDUCED TO ENGLISH ... ix

MAGNETISM ... 1
- TERRESTRIAL MAGNETISM ... 15
- DIAMAGNETISM ... 39
- CHRONOLOGY OF MAGNETISM ... 43

FRICTIONAL OR STATICAL ELECTRICITY—

- FIRST PRINCIPLES ... 45
- STATICAL INDUCTION ... 51
- THEORETICAL VIEWS ... 57
- DISTRIBUTION OF ELECTRICITY ... 67
- ELECTROMETERS AND ELECTROSCOPES ... 71
- ELECTRIC MACHINES ... 75
- BOUND ELECTRICITY ... 85
- ATMOSPHERIC ELECTRICITY ... 97
- CHRONOLOGY OF FRICTIONAL ELECTRICITY ... 105

GALVANISM ... 107
- ACTION OF GALVANIC PAIR, OR SINGLE CELL ... 107

GALVANIC BATTERY AND VARIOUS FORMS OF CELLS—

  - GALVANIC BATTERY ... 129
  - DIFFERENT FORMS OF THE GALVANIC BATTERY ... 131
- MEASURERS OF CURRENT STRENGTH ... 140

GALVANISM—*continued:* PAGE

RESISTANCES TO THE CURRENT—OHM'S LAW—

RESISTANCES TO THE CURRENT....147
OHM'S LAW....151
THE PHYSIOLOGICAL, HEATING, AND LUMINOUS EFFECTS OF THE GALVANIC CURRENT....157
ELECTROLYSIS, OR ELECTROLYTIC EFFECT OF GALVANIC CURRENT....161
CHRONOLOGY OF GALVANISM....167
ELECTRODYNAMICS—ELECTRO-MAGNETISM—CURRENT AND MAGNETO-ELECTRIC INDUCTION...171
ELECTRODYNAMICS....171
ELECTRO-MAGNETISM....178
CURRENT INDUCTION....183
MAGNETO-ELECTRIC INDUCTION—MAGNETO-ELECTRICITY....195
CURRENTS INDUCED BY MAGNETS IN COILS OF WIRE .196
CURRENTS INDUCED BY MAGNETS IN CONDUCTING-PLATES....202
MEASUREMENT OF CURRENT ELEMENTS IN ABSOLUTE UNITS —WORK AND HEAT PRODUCED BY THE CURRENT....205
THERMO-ELECTRICITY....214

PRACTICAL APPLICATIONS OF CURRENT ELECTRICITY—

ELECTRO-METALLURGY....219
ELECTRIC LIGHT....222
EXPLODING GUNPOWDER AT A DISTANCE....227
ELECTRIC CLOCKS....229
ELECTRO-MAGNETIC MACHINES....232
ELECTRIC TELEGRAPH....234
THE TELEPHONE....257

APPENDIX—

WILDE'S MAGNETO-ELECTRIC MACHINE....259
CONSTRUCTION OF INDUCTION COILS....265
ELECTRICITY AND ELECTRIC FORCE....271
THE ATLANTIC TELEGRAPH....278

INTRODUCTION.

All electric phenomena are studied under three heads—Statical Electricity, Current Electricity, and Magnetism. Statical Electricity investigates the properties of electricity which is insulated, or which is only tending to discharge. It is usually got by friction, and hence statical electricity and frictional electricity are frequently used as synonymous. Frictional electricity as it is usually studied, however, not only treats of electricity in its statical condition, but of electricity passing in a single discharge or momentary current. In fact, a body is never charged except by means of discharge in some part of the line of action. Statical electricity always occurs in a dual form, namely, as positive and negative electricity, the characteristic property of which is attraction and repulsion. When positive and negative electricity neutralise each other through a conductor, the conductor shews no trace of either, but becomes possessed of entirely new properties, which are characteristic of electricity in discharge or in motion. A continued discharge constitutes a current. Current Electricity, also called Dynamical Electricity, is chiefly obtained from chemical action (Galvanism), from mechanical action (Magneto-electricity), and from heat (Thermo-electricity). The properties of the current are manifested partly in its path, partly external to it. The current in its path possesses chemical, thermal, and physiological powers. External to its path, its action is closely allied with magnetism. When the path of the current has the form of a spiral, it possesses properties almost identical with those of the magnet. The distinguishing property of the current external to its path, or of magnetism, is attraction and repulsion, but with conditions differing from those of positive and negative electricity. Magnetism thus appears to form a branch of current electricity. The action of magnets on each other, however, which properly constitutes the science of magnetism, may be studied quite apart from their apparent electric constitution. As the action of the earth on the magnetic needle must be understood before current strength can be measured, magnetism usually forms the first step in the science of electricity.

EXPLANATION OF ABBREVIATIONS, &c., USED THROUGHOUT THE WORK.

+	stands for	Positive.
—	〃 〃	Negative.
E.	〃 〃	Electricity.
Fr.	〃 〃	French.
Ger.	〃 〃	German.
C	〃 〃	Centigrade Thermometer.
F	〃 〃	Fahrenheit's 〃

( ) refers to the article given within; or means, when the number is large, a date.

FRENCH MEASURES REFERRED TO REDUCED TO ENGLISH.

1 Metre . is equal to 39·37 inches, about 40 inches.
1 Millimetre.......... ·03937 〃 〃 $\frac{1}{25}$ of an inch.
1 Centimetre .... ·3937 〃 〃 $\frac{2}{5}$ 〃
1 Cubic Centimetre... ·061 cubic inches, about $\frac{1}{16}$ of a cubic inch.
1 Gramme .... 15·43 grains troy, 〃 $\frac{1}{31}$ of an ounce troy.

A degree of the Centigrade thermometer is $\frac{9}{5}$ of a degree of Fahrenheit's thermometer. Any particular temperature on the Centigrade scale is reduced to Fahrenheit's by multiplying it by $\frac{9}{5}$ and adding 32°.

ELECTRICITY.

MAGNETISM.

1. **Magnetism** is the power which certain bodies called magnets have to attract iron. Magnets are of two kinds, *natural* and *artificial.* Natural magnets consist of the ore of iron called magnetic, familiarly known as loadstone, the chemical composition of which is given by the formula Fe_3O_4. This ore, although capable of becoming magnetic, occurs only occasionally naturally magnetised. The loadstone appears to have been first discovered in Magnesia, in Asia Minor, hence the name *magnet.* Artificial magnets are, for the most part, straight or bent bars of tempered steel, which have been magnetised by the action of other magnets, or of the galvanic current. No substance is indifferent to the magnet, though iron is most of all affected by it.

2. *Polarity of the Magnet.*—The power of the magnet to attract iron is by no means equal throughout its length. If a small iron ball be suspended by a thread, and a magnet (fig. 1) be passed along in front of it from one end to the other, it is powerfully attracted at the ends, but not at all in the middle, the magnetic force increasing with the distance from the middle of the bar. The ends of the magnet where the attractive power is greatest are called its poles. The concentration of free magnetic force at the poles of a magnet may be also shewn by

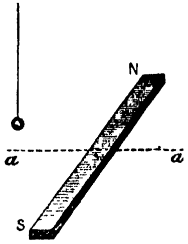


Fig. 1.

dipping it in iron filings, when a tuft of filings adheres to each extremity of it, and the middle is left bare. By causing a magnetic needle moving horizontally to vibrate in front of the different parts of a magnet placed vertically, and counting the number of vibrations, the rate of increase of the magnetic intensity may be exactly found, as will be afterwards shewn.

Fig. 2 gives a graphic view of this increase. NS is the magnet; the lines *n*N, *aa*, &c., represent the magnetic intensities at the points N, *a*, &c., of the magnet; and the curve of

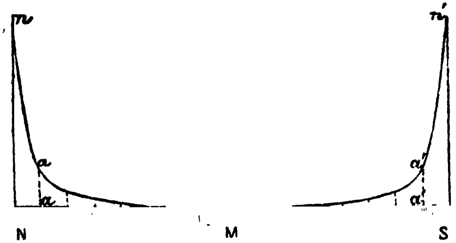


Fig. 2.

magnetic intensity, *na*M*a'n'*, is the line formed by the extremities of all the upright lines. It will be seen from the figure that the force of both halves, taking M as the dividing-point, is disposed in exactly the same way, that for some distance on either side of the middle or neutral point there is an absence of force, and that its intensity increases with great rapidity towards the ends. The centres of gravity of the areas MN*n* and MS*n'* are the poles of the magnet, which must therefore be situated near, but not at the extremities.

The *lines of magnetic force* proceeding from the poles of a magnet may be shewn by putting a piece of stiff drawing-paper over a strong magnetic bar, and strewing fine iron filings over it. Not only is the position of the magnet below shewn on the paper (fig. 3), but the particles of iron arrange themselves in lines which mark out the *magnetic curves* or lines of force. A magnetic curve is that described by the centre of gravity of a small needle, free to move any way when it is moved always in the direction pointed out by the needle from one pole of a magnet to the other.

The entire space through which a magnet diffuses its influence has been termed by Faraday its *magnetic field.* A uniform magnetic field is one in which the lines of force are parallel to each other, such as any small space in the field at some distance from the poles. Any station on the earth's surface is also a uniform field. The *moment* of a magnet is the force lodged in one of its poles multiplied by the distance between them.

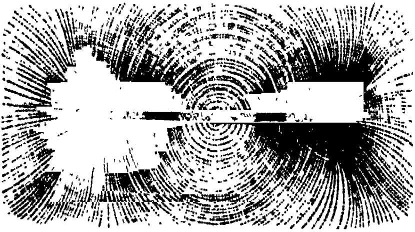


Fig. 3.

If between the magnet and the ball in fig. 1 a sheet of pasteboard, or any other material not containing iron, be interposed, the action of the former on the latter would not be lessened. It is the peculiarity of magnetic action that it is transmitted through all substances not decidedly magnetic with equal facility. Most substances are thus, so to speak, magnetically transparent.

3. A magnet has, then, two poles or centres of free magnetic force, each having an equal power of attracting iron. This is the only property, however, which they possess in common, for when the poles of one magnet are made to act on those of another, a striking dissimilarity is brought to light. To shew this, let us suspend a magnet, NS, fig. 4, by a stirrup of paper, M, hanging from a cocoon thread (or any fine thread without torsion). When the magnet is left to itself, it takes up a fixed position, one end keeping north, and the other south. The north pole

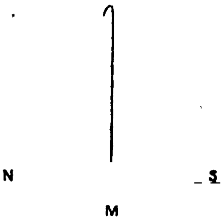


Fig. 4.

cannot be made to stand as a south pole, and *vice versâ*; for when the magnet is disturbed, both poles return to their original positions. Here, then, is a striking dissimilarity in the poles, by means of which we are enabled to distinguish them as *north pole* and *south pole.* When thus suspended, let us now try the effect of another magnet upon it, and we shall find that the pole of the suspended magnet that is attracted by one of the poles of the second magnet is repelled by the other, and *vice versâ*; and where the one pole attracts, the other repels. If, now, the second magnet be hung like the first, it will be found that the pole which attracted the north pole of the first magnet is a south pole, and that the pole which repelled it is a north pole. We thus learn, that *each magnet has two poles, the one a north, and the other a south pole, alike in their power of attracting soft iron, but differing in their action on the poles of another magnet, like poles repelling, and unlike poles attracting, each other.*

When a small magnetic bar, or needle, as it is called (fig. 5), is finely balanced by means of a small inverted agate cup on a fine needle of steel fixed to a stand, it may be used as a magnetoscope to indicate whether a piece of iron or steel is magnetic or not. If both poles of the needle are attracted indifferently by any end of it, it is not magnetic; but if one pole be attracted and the other repelled, the piece of iron or steel under examination is magnetic.

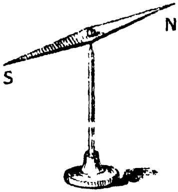


Fig. 5.

4. It might be thought that, by dividing a magnet at its centre, the two poles could be insulated, the one half containing all the north polar magnetism, and the other the south. When this is done, however, both halves become separate magnets, with two poles in each—the original north and south poles standing in the same relation to the other two poles called into existence by the separation. *We can therefore never have one kind of magnetism without having it associated in the same magnet with the same amount of the opposite*

magnetism. It is this double manifestation of force which constitutes the *polarity* of the magnet, and a bar of iron which is made to assume these poles is said to be polarised.

5. The fact of the freely suspended magnet taking up a fixed position, has led to the theory, that the earth itself acts much in the same way as a huge magnet, with its north and south magnetic poles in the neighbourhood of the poles of the axis of rotation, and that the magnetic needle or suspended magnet turns to them as it does to those of a neighbouring magnet. All the manifestations of terrestrial magnetism give decided confirmation of this theory. It is on this view that the French call the north pole of the magnet the south pole (*pôle austral*), and the south the north pole (*pôle boréal*); for if the earth be taken as the standard, its north magnetic pole must attract the south pole of other magnets, and *vice versâ.* In England and Germany, the north pole of a magnet is the one which, when freely suspended, points to the north, and no reference is made to its relation to the magnetism of the earth.

6. *Form of Magnets.*—Artificial magnets are either bar magnets or horseshoe magnets. When powerful magnets are to be made, several thin bars of steel are placed side by side with their poles lying in the same way. They end in a piece of iron, to which they are bound by a brass screw or frame. Three or four of these may be put up into the bundle, and these again into bundles of three and four (fig. 6). Such a collection of magnets is called a *magnetic magazine or battery.* A magnet of this kind is more powerful than a solid one of the same weight and size, because thin bars can be more strongly and regularly magnetised than thick ones. Fig. 7 is a horseshoe-magnetic magazine. The central lamina protrudes slightly beyond the other, and it is to it that the armature is attached, the whole action of the magnet being

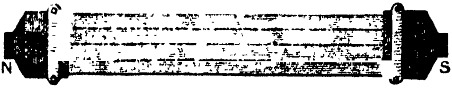


Fig. 6.

concentrated on the projection. A natural magnet is shewn in fig. 8. It is a parallelopiped of magnetic iron ore, with pieces of soft iron, NN and SS, bound to its poles by a brass frame encircling the whole. The lower ends of the soft iron bars act as the poles, and support the armature, A.

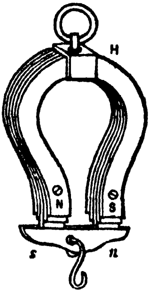


Fig. 7.

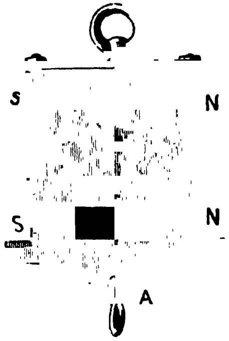


Fig 8.

7. *Magnetic Induction* (Fr. *influence,* Ger. *Vertheilung*).—When a short bar of soft iron, *ns* (fig. 9), is suspended from one end, S, of the magnet, NS, it becomes for the time powerfully magnetic. It assumes a north and south pole, like a regular magnet, as may be seen by using the small magnetic needle (fig. 5); and if its lower end, *s*, be dipped into iron filings, it attracts them as a magnet would do. When it is taken away from NS, the filings fall off, and all trace of magnetism disappears. It need not be in actual contact to

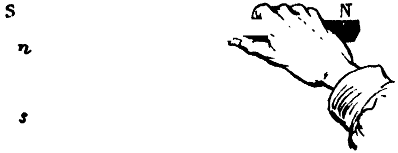


Fig. 9.

shew magnetic properties; when it is simply brought near, the same thing is seen, though to a less extent. If the inducing magnet be strong enough, the induced magnet, *ns*, when in contact, can induce a bar like itself, placed at its extremity, to become a magnet; and this second induced magnet may transmit the magnetism to a third; and so on, the action being, however, weaker each time. If a steel bar be used for this experiment, a singular difference is observed in its action; it is only after some time that it begins to exhibit magnetic properties, and, when exhibited, they are feebler than in the soft iron bar. When the steel bar is removed, it does not part instantly with its magnetism, as the soft iron bar, but retains it permanently. Steel, therefore, has a force which, in the first instance, resists the assumption of magnetism; and, when assumed, resists its withdrawal. This is called the *coercitive force.* The harder the temper of the steel, the more is the coercitive force developed in it. It is this force also, in the loadstone, which enables it to retain its magnetism.

The polarised condition of iron under induction seems to indicate that a substance which is attracted by the magnet must itself become magnetic. The attraction between a magnet and soft iron is thus essentially the same as that between two magnets. Hence we may conclude that *magnetic attraction and repulsion take place only between magnets temporary or permanent.*

8. *Magnetic Armatures or Keepers* (Fr. *armures*, Ger. *Armaturen,Anker* in the case of horseshoe magnets) are pieces of soft iron that are placed at the extremities of magnets to preserve their magnetic power. When magnets are allowed to remain any length of time without such appendages, in consequence of the disturbing influence of terrestrial magnetism they lose considerably in strength; but when they are provided with them, their magnetism is kept in a state of constant activity, and thereby from this disturbance. The reason of this is to be attributed to magnetic induction. Referring to fig. 7, the north pole, N, of the horseshoe magnet, NHS, acting on the armature, *sn*, induces it to become a magnet, having its south pole, *s*, next to N, and its north pole, *n*, at the opposite

extremity. The pole S, by virtue of its magnetic affinity, powerfully attracts the north pole, *n*, thus formed, and adds its own inducing influence to heighten the magnetic condition previously induced in the armature by the pole N. The armature, from the combined action of both poles of the horseshoe magnet, is thus converted into a powerful magnet, with its poles lying in an opposite direction to that of the primary poles. The original magnet is, in consequence, brought into contact with one of its own making, the exact counterpart of itself, the action of which being much more potent than that of the earth, effectually shields it from terrestrial disturbance. The attachment of the armature to the magnet is greater when its contact with the magnet is made by a rounded edge instead of a plane surface. It is due to the same mutual attractions that a much larger weight can be suspended from the armature thus placed, than what the single poles can together sustain. Bar magnets may be armed in the same way by laying them at some distance parallel to each other, with their unlike poles towards the same parts, and then connecting their extremities by two pieces of soft iron (fig. 12). When a magnet, such as a compass-needle, is free to take up the position required by the magnetism of the earth, the earth itself plays the part of an armature.

9. *Magnetisation.—By Single Touch* (Fr. *simple touche*, Ger. *einfacher Strich*). The steel bar to be magnetised is laid on a table, and the pole of a powerful magnet is rubbed a few times (ten to twenty) along its length, always in the same direction. If the magnetising pole be north, the end of the bar it first touches each time becomes also north, and the one where it is lifted south. The same thing may be done by putting, say the north magnetising pole first on the middle of the bar, then giving it a few passes from the middle to the end, returning always in an arch from the end to the middle. After doing the same to the other half with the south pole, the magnetisation is complete. The first end rubbed becomes the south, and the other the north pole of the new magnet.—*By Divided Touch* (Fr. *touche séparée*, Ger. *getrennter Strich*). This method is shewn in fig. 10. The bar, *ns*, to be magnetised is placed on a piece of wood, W, with its ends abutting on

the extremities of two powerful magnets, NS and SN. Two rubbing magnets are placed with their poles near, but not touching, on the middle of *ns*, inclined at an angle rather less than 30° with it. They are then simultaneously moved away from each other to the ends of *ns*, and brought back in an arch again to the middle. After this is repeated a few times, the bar *ns* is fully magnetised. The disposition of the poles is shewn in the figure by the letters N or *n*, meaning a north, and S or *s*, a south pole. This method communicates a very regular magnetism, and is employed for magnetic needles, or where accuracy is needed.—The magnetisation by *Double Touch* (Fr. *double touche*, Ger. *doppel Strich*). The arrangement at the commencement of the double touch is the same as that shewn in fig. 10, only a small piece of wood is placed between the two stroking magnets to prevent contact, and their angle with the bar to be magnetised is less from 15° to 20°. The two magnets are drawn along from the middle to one end, and then back to the other, and so backwards and forwards from ten to twenty times, and lifted from the magnetised bar again at the middle. Care must be taken that both ends have been stroked the same number of times, and that the lower poles of neither of the stroking magnets go beyond the ends of the bar. When this is done to both upper and lower surfaces, the bar is fully magnetised. This method is used for thick bars. It communicates a powerful, but sometimes irregular magnetism, giving rise, when the poles of the stroking magnets are not near each other, to *consecutive poles* (Ger. *Folgepuncte*)—that is, to more poles than two in the magnet, as if say three magnets were placed in a line, the middle one lying in the opposite way to the other two.

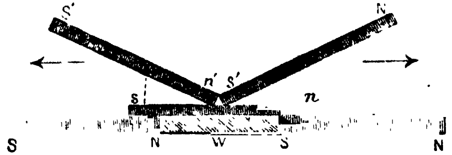


Fig 10.

For horseshoe magnets, Hoffer's method is generally followed. The inducing magnet (fig. 11) is placed vertically on the magnet to be formed, and moved from the ends to the bend, or in the opposite way, and brought round again, in an arch, to the starting-point. A soft iron armature is placed at the poles of the induced magnet. That the operation may succeed well, it is necessary for both magnets to be of the same width. The same method may also be followed for magnetising bars. The bars (fig. 12) NS and N′S′, with the armatures *ab* and *cd*, are placed so as to form a rectangle; and the horseshoe magnet is made to glide along both in the way just described.

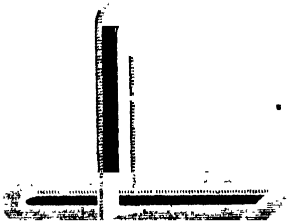


Fig. 11.

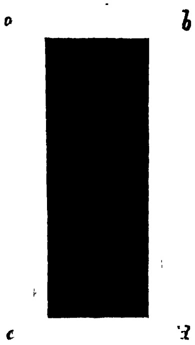


Fig. 12.

By the Galvanic Current.—This is done by placing the bar to be magnetised inside a flat coil of insulated wire, through which a galvanic current is circulating, and moving it backwards and forwards as in double touch. The circuit is closed when at the beginning of the operation the middle of the bar is at the coil, and opened when the bar stands again at the middle at the end of it. The magnetism induced in this way is much weaker than that got when the same strength of current is employed through the intervention of an electro magnet. Thick bars or horseshoes of the hardest temper can be easily magnetised with a strong electro-magnet by rubbing each half of the bar or horseshoes on a different pole, beginning at the middle, after the method of single touch. Electro-magnets far transcend permanent magnets in power.

Magnetisation by the Earth.—The inductive action of terrestrial magnetism is a striking proof of the truth of the theory already referred to, that the earth itself is a magnet. When a steel rod is held in a position parallel to the dipping-needle, it becomes, in the course of time, permanently magnetic. This result is reached sooner when the bar is rubbed with a piece of soft iron. A bar of soft iron held in the same position is more powerfully but only temporarily affected, and when reversed, the poles are not reversed with the bar, but remain as before. If when so held it receive at its end a few sharp blows of a hammer, the magnetism is rendered permanent, and now the poles are reversed when the bar is reversed. The torsion caused by the blows of the hammer appears to communicate to the bar a coercitive force. We may understand from this how the tools in workshops are generally magnetic. Whenever large masses of iron are stationary for any length of time, they are sure to give evidence of magnetisation, and it is to the inductive action of the earth's poles acting through ages that the magnetism of the loadstone is to be attributed.

10. *Saturation Point.*—Magnets, when freshly magnetised, have sometimes more magnetism than they can retain permanently. In that case, they gradually fall off in strength, till they reach a point at which their strength remains constant. This is called the *point of saturation.* If a magnet has not been raised to this point, it will lose nothing after magnetisation. We may ascertain whether a magnet is at saturation by magnetising it with a more powerful magnet, and seeing whether it retains more magnetism than before. The saturation point depends on the coercitive force, or temper, of the magnet, and not on the power of the magnet with which it is rubbed. When a magnet is above saturation, it is soon reduced to it by repeatedly drawing away the armature from it. After reaching this point, magnets will keep the same

strength for years together if not subjected to rough usage.

11. *Power of Magnets.*—The power of a horseshoe magnet is usually tested by the weight its armature can bear without breaking away from the magnet. Häcker gives the following formula for this weight: $W = a\sqrt[3]{m^2}$; W is the charge expressed in pounds; a, a constant to be ascertained for a particular quality of steel; and m is the weight in pounds of the magnet. He found, in the magnets that he constructed, a to be 12·6. According to this value, a magnet weighing 2 oz. sustains a weight of 3 lbs. 2 oz., or twenty-five times its own weight; whereas a magnet of 100 lbs. sustains only 271 lbs., or rather less than three times its own weight. Small magnets, therefore, are stronger for their size than large ones. The reason of this may be thus explained: Two magnets of the same size and power, acting separately, support twice the weight that one of them does; but if the two be joined, so as to form one magnet, they do not sustain the double, for the two magnets being in close proximity, act inductively on each other, and so lessen the conjoint power. Similarly, several magnets made up into a battery have not a force proportionate to their number. Large magnets in the same way may be considered as made up of several laminæ, interfering mutually with each other, and rendering the action of the whole very much less than the sum of the powers of each. The best method of ascertaining the strength of bar-magnets is to cause a magnetic needle to oscillate at a given distance from one of their poles, the axis of the needle and the pole of the magnet being in the magnetic meridian. These oscillations observe the law of pendulum motion, so that the force tending to bring the needle to rest is proportionate to the square of the number of oscillations in a stated time.

12. *Action of Magnets on each other.*—Coulomb discovered, by the oscillation of the magnetic needle in the presence of magnets in the way just described, that *when magnets are so placed that two adjoining poles may act on each other without the interference of the opposite poles*, that is, when the magnets are large compared with the distance between their centres, *their attractive or repulsive force varies inversely as the square of*

the distance. The manner in which he proved this will be best understood by taking a case. The suspended needle *ns* (fig. 13), when disturbed from its position of rest, makes ten oscillations a minute under the force of the earth's magnetism. When the pole S of the magnet NS, which is so long that the pole N is beyond the sphere of action, is placed at a distance of two inches from *n*, the number of oscillations in the minute is 36. When at four inches, 20. In the last two cases the oscillations are made under the combined force of the magnetism of the earth and of the magnet. This combined effect at two inches stands to the terrestrial magnetism as 36^2 is to 10^2, and at four inches as 20^2 to 10^2. Now, the difference between 36^2 and 10^2, divided by the difference between 20^2 and 10^2, gives the relative powers of the magnet on the needle at two and at four inches. But $36^2—10^2$, or 1196, is very nearly four times $20^2—10^2$, or 300, so that the magnet is only one-fourth as powerful at four inches as it is at two. The attractive powers are thus as 1^2 to 2^2—i. e., inversely as the squares of the distances. If the poles had been like, the same would hold of the repulsive power. The law of the *action of magnets on soft iron by induction* was ascertained by Sir William Snow Harris in 1827. It is as follows: *The magnetic development in the soft iron is directly proportional to the power of the inductive force, and inversely as the distance.*

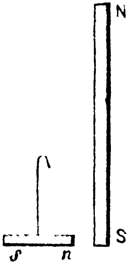


Fig. 13.

In the measurement of magnetic forces, repulsion is measured when practicable in preference to attraction; because attraction may be wholly or partially due to induction, whereas, repulsion can only arise from the original forces in each.

13. *Effect of Heat on Magnetism.*—A magnet loses in power as it rises in temperature, and as it cools again it acquires again a portion of its lost strength. When it is raised to the same temperature several times, or when it is kept a sufficient length of time at it, it reaches a condition in which it suffers

no further permanent loss by being again heated up to the same temperature. The more strongly the bar is magnetised, the less is it affected by temperature. The change of intensity produced by ordinary temperatures is little, if anything. At a white heat, a magnet loses permanently all trace of magnetism. When, however, it is again tempered and magnetised, it resumes its magnetic properties. Barlow found that soft iron steel and cast iron, when temporarily magnetic *—that is, when under induction—have a greater magnetic capacity as their temperature rises until they reached a blood-red heat. Beyond this,* they become less susceptible to the influence of the magnet, and at a white heat they are quite indifferent to it. The temperatures at which other substances affected by the magnet become indifferent to it, is different from that of iron. Cobalt is attracted by the magnet at the highest temperatures, and nickel loses this property at 662° F.

14. *Theories of Magnetism.*—The best known theory of magnetism is that of the two fluids. It is thought that the power of the magnet arises from two magnetic fluids existing in it. These fluids are considered to be attractive of the matter of the magnet and of each other, but repulsive ot themselves. By magnetisation, the fluids which, when they exist together, exhibit no magnetic properties are made to separate. At first, it was thought that in a magnet each fluid became insulated on its own half of the magnet, but this hypothesis was found to be untenable from the fact that when a magnet was broken in the middle, each fragment had both kinds of magnetism, like the original magnet. To meet this inconsistency, it was next supposed that each particle of the magnet was itself a magnet like the whole, and that break it where you may, you have in the pieces the same constitution as in the whole. Magnetisation was considered only to separate the fluids in each particle. A more recent theory suggests, that all substances capable of becoming magnetic consist of particles, each of which is a permanent magnet; that these infinitesimal magnets have their poles turned in all different directions, so as to neutralise each other when the whole is not magnetic; that magnetisation has the effect of bringing the poles of these particles round so as to lie in

the same direction; that this coincidence of poles in the case of soft iron takes place only when the iron is under induction; that in the case of steel it takes place permanently; and that the degree of magnetisation is due to the completeness of the coincidence. This last way of conceiving of the composition of a magnet is both simple and satisfactory. The fluid theory of magnetism simply describes its phenomena under the figure of two fluids. *Ampere's theory of the electric constitution of a magnet*, which shall be afterwards described, introduces an entirely novel view of it.

Terrestrial Magnetism.

15. *The Directive Action of Terrestrial Magnetism.*—The action of the magnet is so allied with the magnetism of the earth, that we cannot study the one apart from the other. The action of the earth on a magnet is simply *directive;* that is, it determines the position of the magnet relatively to the cardinal points of the horizon, but effects no strain or tendency to translation on the point on which the magnet is balanced. This is usually shewn by making the centre of a magnetic needle rest on a piece of cork floating on water. The needle when so sustained comes round to a north and south position, but the float remains at the same point on the surface of the liquid. The reason of this may be given thus: the magnetic poles of the earth are so far distant from the magnet, that, practically, the north and south poles of the magnet are at equal distances from them. Accordingly, whatever attraction, say the north pole of the earth has to the north pole of the magnet, it exerts an equal repulsion on the south pole of the magnet. The two effects counteract each other. The same holds for the action of the south terrestrial pole. The combined effect of the two terrestrial poles, in attracting or repelling the magnet as a whole, is thus null, and is limited to fixing the direction of the needle when at rest.

We are so accustomed to see the directive power of the earth's magnetism exhibited in the compass, that we are inclined to think that it is only exerted on a needle moving in a horizontal plane. Such, however, is not the case. When a needle is so supported that it can move freely in a vertical plane, it does not remain horizontal, but inclines towards the ground. It is impossible so to support a magnetic needle that it is at the same time free to move in a horizontal and in a vertical plane. The power of the earth in determining the position of the needle in a vertical and in a horizontal plane, must be exhibited by two separate needles. If it were possible to hang a needle in the air, so as to leave it perfectly free to take up any position, it would shew us fully the directive action of the earth. Such a needle would not only point north and south, but when so pointing would, at most places on the earth's surface, make a certain angle with the horizon. The position taken up by such a needle would shew the direction in which the earth's magnetism acts, and if we knew, in addition to this position, the force that kept it in that position, we should know the direction and amount of the earth's magnetic force for the place of observation. In consequence of our inability to suspend a needle so as to give it a perfectly free universal motion, the direction must be ascertained by two separate observations, viz., the position of rest of a needle moving in a horizontal plane, and that of one moving in a vertical plane. The former of these is termed the *declination*, and the latter the *inclination* of the needle. *A complete knowledge of the earth's magnetism at any place therefore implies that three things are known—declination, inclination, and intensity.* These are termed the *magnetic elements* (Ger. *Constanten*) of the place.

16. *Definition of the Magnetic Elements.—Declination.*—When a magnetic needle is suspended or made to rest on a point so as to be free to move in a horizontal plane, it finds its position of rest in a line joining two fixed points on the horizon; and when made to leave that position, after several oscillations, it returns to it again. At certain places on the earth's surface, these two points are the north and south points of the horizon; but generally, though near,

they do not coincide with these. A vertical plane passing through the points on the horizon indicated by the needle, is called the *magnetic meridian*, in the same way that a similar plane, passing through the north and south points, is known as the astronomical meridian of the place. The angle between the magnetic and astronomical meridians is termed the declination or variation of the needle. Thus, if NS (fig. 14) be the line of the astronomical meridian, and *ns* the line joining the poles of the needle, the angle NC*n* is the declination. The declination is east or west, according as the magnetic north lies east or west of the true north.

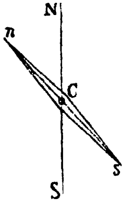


Fig. 14.

Dip or Inclination.—If a magnetic needle be supported so as to be free to move vertically, it does not at most places on the earth's surface rest in a horizontal position, but inclines more or less from it. If the vertical plane in which the needle moves is the magnetic meridian of the place, the angle between the needle and the horizontal line is called the dip or inclination of the needle. Thus, if the needle (fig. 15), NS, be supported at its centre, C, so as to be free to move vertically, the plane of the paper being supposed to be that of the magnetic meridian, the angle NC*a* is the dip.

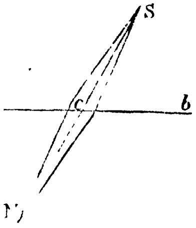


Fig. 15.

Intensity.—The amount of force which brings a magnetic needle, of unit size and strength, capable of universal motion round its centre of gravity, when driven from the position in which it rests under the influence of terrestrial magnetism, back to that position again, constitutes magnetic intensity. The needle may be looked upon as a magnetic pendulum, with magnetism, instead of gravity, as the force acting on it.

17. ***Resolution of Total Magnetic Force.***—Let NS (fig. 16) be a needle adjusted on the point *p*, so as to move in a horizontal

plane. It is represented as lying in the magnetic meridian. It is supposed to be in a northern latitude, so that the north pole of the magnet is attracted, and the south pole repelled, by an equal force. The total magnetic force of the earth, represented by the lines NC and S*c*, in magnitude and direction, tends, when acting on N, to draw it down, when on S, to send it up, with an equal force. The two equal and opposite

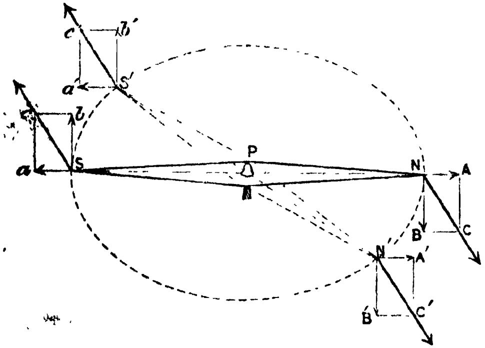


Fig. 16.

parallel forces, NC and S*c*, form with the needle a couple tending to make it rotate in the direction of the hands of a watch. To keep the needle in a horizontal position, the south end of it is made slightly heavier than the north end. The total forces, NC and S*c*, may be resolved each into two others acting vertically and horizontally; that is, perpendicular to, and in the plane of, the needle's motion. The construction is exactly alike, so far as magnitude is concerned, at N and S, but it is opposite in direction. The vertical resolved parts of the earth's magnetism, which are alone concerned in determining the position of a needle moving in a vertical plane, are NB and S*b*. These being counteracted by gravity, have no effect on the needle. NA and S*a* are the horizontal resolved parts, and they alone are concerned in the motion of a needle free to move in a horizontal plane. NA and S*a*, being equal and opposite, counteract each other. Suppose, now, the needle moved from its position of rest to that shewn by the dotted needle, N′S′. The earth's magnetism must act on N′ and S′ as it did on N and S, and consequently a similar resolution may be made. This resolution takes place in planes parallel to the former, and perpendicular to the circle or plane in which the needle moves. The vertical resolved parts, N′B′ and S′b′, are counteracted as before by the supporting point, but the horizontal resolved parts, N′A′ and S′a′, form a couple, bringing the needle back to its first position. They act, however, obliquely on the needle, and to ascertain their effective force we must again resolve them as done in fig. 17. The resolution takes place in this case in the plane of the needle. The parts N′F and S′f, being equal and opposite, counteract each other, and the two effective parts, N′E and S′e, alone make the needle rotate. Let NC = T, the total intensity; NB = I, the vertical intensity; NA = H, the horizontal intensity; angle ANC = i, the angle of dip; then I = T sin. i, H = T cos. i, I = H tan. i.

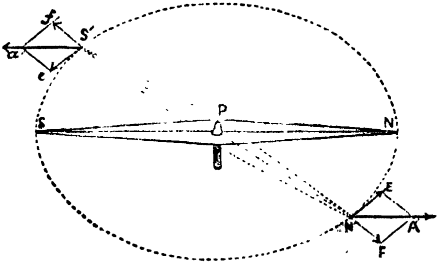


Fig. 17.

18. INSTRUMENTS FOR ASCERTAINING MAGNETIC ELEMENTS.—*Declinometer.*—Instruments for determining magnetic declination are called declination needles or declinometers. In these instruments there are two things essential—the means of ascertaining the astronomical meridian, and a needle for shewing the magnetic meridian. Fig. 18 represents a common form of the declinometer. Upon a tripod provided with levelling screws stands the pillar P, to which is fixed the

graduated azimuthal circle CC. The compass-box B, with the vernier V, attached to it, moves on the azimuthal circle by means of a pivot at the pillar P. Two uprights, U, U, are fixed to the side of the compass-box, on the tops of which rests the axis of the telescope, T. A gradu-

the bottom of one of the uprights, and the angle of elevation of the telescope is marked by the vernier on the arm E, attached to the axis of the telescope. A level, L, is also hung on the axis of the telescope, for adjusting the instrument. Inside the compass-box is another graduated circle, F, the line joining the zero-points of which is parallel to the axis of the telescope. All the fittings are in brass or copper, iron, of course, being unsuitable. It will be easily seen that the compass-box and telescope move round as one piece on an axis passing through the centre of the azimuthal circle. When an observation is made, the telescope is pointed to a star whose position with regard to the astronomical meridian is known at the time of observation. The telescope with the compass-box is then brought the proper number of degrees on the azimuthal circle, until its axis is in the meridian of the place. If, when the telescope is in this position, the north end of the needle stand at the zero-point of the inner circle, the declination would be 0°; but if it lie east or west of this point, the declination is shewn by the degree at which the needle stands. It is difficult to construct a needle so that the line joining its poles exactly coincides with the line joining its visible extremities. If this

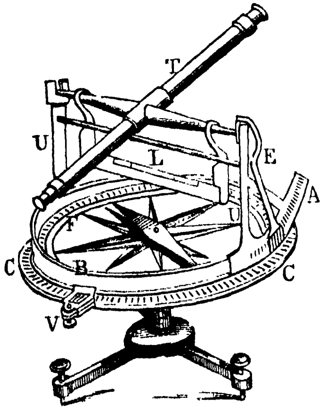


Fig. 18.

coincidence be not perfect, the geometrical axis of the needle according to which the reading is made lies to the right or left of the magnetic axis, and consequently of the true reading. To remedy this, the needle is so made that it can rest either on its lower or upper surface. In finding the true reading, the position of the needle is marked, and then it is turned upside down, and again marked, the mean of the two readings giving the true one. This is easily seen in fig. 19. The declination of the needle may be also ascertained by the dipping needle.

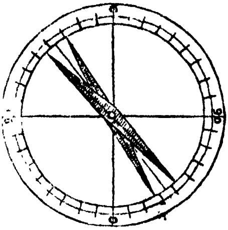


Fig. 19.

Gauss's Magnetometer.—A declinometer like the one just described, can only give the declination approximately. To be quite exact, the needle would require to be very long, so as to allow the divisions of the circle on which it moves to shew very small angles. This, however, would be attended with the objection that a very long needle moves with considerable friction on its axis, so that what we should gain in the number of divisions on the circle we should lose in the sensibility of the needle. Gauss's magnetometer obviates this objection. Fig. 20 gives a general idea of the action of the instrument.

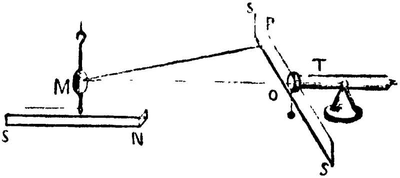


Fig 20.

NS is a magnetic bar, suspended by a wire or a few untwisted filaments of cocoon silk sufficient to sustain its weight, which is a few pounds. It is enclosed in a glass case, not shewn in the figure, to shield it from currents of air. On the rod at the centre of the bar by which it is suspended a small mirror, M, is fixed, the plane of which is at right angles to the line joining the poles of the bar. A few yards from the bar, a theodolite, T, and a scale, S, about a yard long, are placed, the one a little above, the other below the mirror, so that the divisions of the scale may be seen reflected at the cross-wires of the theodolite. A small plummet hangs down from the object-glass of the theodolite, the thread of which stands in front of the zero or middle point of the scale. When the thread of the plummet is seen reflected, the axis of the theodolite is accurately in the magnetic meridian. When a magnetic bar is hung in this way it never stands still, but is constantly making small oscillations, shewing that the magnetic meridian is ever moving to and fro, and is no fixed plane like the astronomical meridian. It is not so much, then, when the reflection of the thread is seen at the cross-wires as when the needle oscillates to equal distances on each side of it, that the axis of the theodolite is in the mean magnetic meridian. This being ascertained, the theodolite has only to be turned to some object known to be in the astronomical meridian, and the difference of the readings gives the declination. The scale is placed at right angles to the magnetic meridian. We shall afterwards find that the needle makes various small deviations from its mean position in the course of the day. These the magnetometer, from its extreme delicacy, is well fitted to record. Suppose, for instance, that the needle appears to oscillate, not round the zero point, but round a point P, say an inch from it. Now, as we know the distance of the scale from the mirror, say it be in this case 15 feet, we can easily tell what the angle PMO is—viz., 19′ 6″ (tan. $\text{PMO} = \frac{\text{PO}}{\text{MO}} = \frac{1}{180}$) from the trigonometrical tables; or by taking 1 inch as the arc of a circle whose radius is 15 feet, and whose circumference of 360° is 3·1416 times 30 feet, it can be shewn by an easy geometrical construction that the apparent angle is twice the angle that the mirror or the magnet describes, so that the real deflection of the needle in this case is 9′ 32″. The observation is here taken as correctly as if a needle 30 feet in length had moved through an angle 9′ 32″, or described an arc of half an inch on a 30-foot circle.

Expert observers can read an angle of 2″ by the magnetometer. It can also be easily understood how, if a lamp be placed where the theodolite is, and be made to transmit a ray of light to the mirror, that this ray would be reflected on the scale, and that if instead of the scale a piece of sensitised photographic paper were placed, and moved upwards or downwards at a given rate, the needle would permanently record its own motions. A self-recording system on this principle, invented by Mr Brooke, is adopted in almost all observatories.

The *Mariner's Compass* (Fr. *boussole*, Ger. *Bussole*) is also a declinometer, for it must be always used with reference to the true north of the region where it acts. It consists of a needle nicely poised on a point, with a cross-bar of copper or brass at its middle. The needle and bar support a card above, which is marked with 32 points, each containing 11° 15′. These are shewn in the annexed figure (fig. 21). The north and south points of this card lie directly over the needle, so that the card, and not the needle, indicates these cardinal points to the observer. The whole is enclosed in a brass or copper bowl. This is placed within a ring, which moves by two pivots in another ring, itself supported by two pivots at right angles to the other two. These two rings are called the *gimbals*. The compass-box and card thus supported remain always horizontal, whatever be the motion of the vessel in which it is placed. Inside the compass-box a vertical black line is marked, called the lubber-line, which is in the axis of the ship or in the line of the ship's motion. The point of the card that lies at the lubber-line shews how the ship is going.

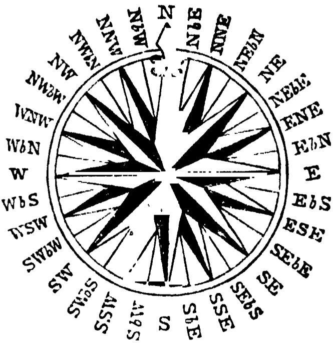


Fig. 21.

The great difficulty connected with the use of the mariner's compass arises from the disturbing influence of the magnetism of the ship. This difficulty is particularly felt in iron vessels, where the deviation of the needle is frequently so considerable as to render the compass almost useless. Various means of obviating this have been suggested; one of these is to place bars of soft iron or magnets in the immediate neighbourhood of the binnacle, which being so placed as to cause a contrary disturbance to that of the iron of the ship, leave the needle comparatively free. This is found to answer well in iron ships plying between British and continental or North American ports; but where, as in the Australian passage, they change considerably their latitude, such an arrangement is found to be worse than useless, as the magnetism of the vessel changing with the latitude causes an ever-varying deviation of the needle. It has likewise been suggested to place a compass as a standard at the mast-head, where it would be comparatively free from the attraction of the vessel, by which the ship's course might be shaped, the ordinary compass being used merely to give immediate direction to the steersman. In the royal navy this error is to a large extent obviated in the following way. A compass is placed so high above the deck as to clear the bulwarks, and allow the bearings of a distant object on shore or a heavenly body to be taken while the ship's head makes a complete circuit. In this way, the deviation caused by the iron of the ship in all different positions may be ascertained, and afterwards taken into account.

Dipping Needle.—The dip of the magnetic needle at any place can be ascertained with great exactness by means of the dipping needle, fig. 22. It consists of a graduated circle, AA, fixed vertically in the frame FF, and moving with it and the vernier V, on the horizontal graduated circle HH. This last is supported by a tripod furnished with levelling screws. At the centre of the circle C, there are two knife-edges of agate, supported by the frame, and parallel to the plane of the circle. The needle, NS, rests on these knife-edges by means of two fine polished cylinders of steel, which are placed accurately at the centre of the needle, and project at right angles from it: so adjusted, the needle moves with little or no friction. It is so made, moreover, that before being magnetised it remains indifferently in any position; after magnetisation, therefore, the dip which it shews is wholly due to the magnetic influence of the earth. It will be seen from fig. 16, that when a needle is capable of vertical motion, the earth's magnetism will swing the needle round until it is as nearly as possible in a line with it. When the needle is in the magnetic meridian, this can be done fully, for the needle can be made to coincide with it in direction. The couple CNSc is in that case a straight line. When the needle moves in a plane at right angles to the meridian, then the vertical component alone affects its position, and places it vertical in a line with itself. In this case BNS*b* is a straight line. Between these two positions the needle shifts from the vertical position to that of the direction of the dip, and is always more inclined to the horizon than in the meridian. We have thus two ways of finding the meridian. When the needle stands upright at 90°, it is at right angles to the meridian; and by moving the vernier over 90°, we can place it in the meridian. Again, that plane in which the inclination of the needle is least is the plane of the meridian. The degree pointed to on the circle when in the magnetic meridian is the angle of dip. The dip may also be got with even more accuracy by observing the effect produced by bars of soft iron placed vertically in the neighbourhood of a declination needle on the needle; but the process is somewhat detailed, and beyond the scope of this book.

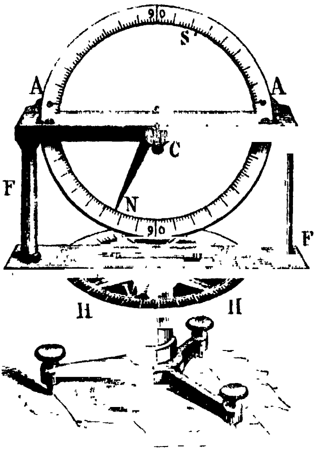


Fig. 22.

Intensity Needles.—The total intensity of the earth's magnetism is got by first ascertaining experimentally its horizontal intensity. The total intensity is got by dividing the horizontal intensity by the cosine of. the angle of dip (17). The horizontal intensity is measured by the number of oscillations that a needle makes when disturbed in a given time. Thus, if at one point on the earth's surface the same needle makes twenty oscillations per minute, and at another twenty-one, the relative horizontal intensities at the two places would be as 20^2 to 21^2, as 400 to 441. If the horizontal intensity of any point on the earth's surface be taken as unity, other intensities may be expressed in terms of it. The method of ascertaining intensity just described is open to objection, as it is difficult to know whether the magnetic condition of the needle remains unaltered during the course of the observations at different stations. Gauss avoided this error by reducing the intensity to an absolute, not a relative standard. This he did by taking into account not only the oscillations of the needle under observation, but also its deflecting power on another needle at a stated distance. The data thus obtained gave him sufficient to divest the magnet of its peculiarity, and enabled him to express the intensity in absolute units. Thus, the horizontal intensity of London (January 1865) is 1·764 metrical units, which signifies that a south pole weighing one gramme, and of an ideal, but definite unit magnetic force, would, supposing it were insulated and free to move in a horizontal plane, acquire a velocity southward of 1·764 metres per second. In British units expressed in feet with the mass of a grain instead of a gramme, the same is 3·826.

Gauss's Bifilar Magnetometer is used for indicating local changes of terrestrial magnetism. It consists essentially of a magnetic bar hung by two threads, as roughly shewn in fig. **23.** So long as the plane of the bar and of the two threads coincide with the magnetic meridian, there is no strain on the threads; but if the points of suspension be turned round, then the bar will take up an intermediate position determined by the intensity of the earth's magnetism striving to put the bar in the meridian, and by the spiral torsion of the threads striving to bring the bar into a line with the points of suspension. The instrument is capable of any amount of delicacy, according as the threads are lengthened or brought near each other. For observation, the threads are so twisted as to put the bar perpendicular to the magnetic meridian. In this position, the small changes of declination that take place in the course of the day may be neglected. The force necessary to twist the bar through any angle is got by experiment, and is used in interpreting the indications of the instrument. A mirror is attached to the bar, and observations taken as with the magnetometer.

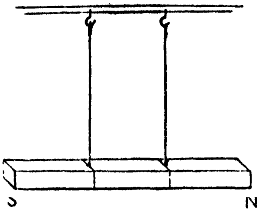


Fig. 23.

19. *Magnetic Charts.*—The magnetic elements have been ascertained with great care at different portions of the earth's surface. The knowledge thus obtained has been embodied in magnetic charts, in which the points at which the declination is the same are joined by lines, and similarly those where the dip and intensity are alike. The lines of equal declination are called isogonic lines; those of equal dip, isoclinic; and those of equal intensity, isodynamic lines. As the magnetism of the earth is subject to a slow secular variation, such charts are only true for the time of observation. The chart, fig. 24, was drawn up by Colonel Sabine for the year 1840, and gives an approximate view of the lines of equal declination for that year. The change since 1840 has been small, so that an isogonic chart for the present time would differ but slightly from it. The chart sufficiently explains itself. Attention may, however, be given to one or two points. The declination is marked on each line. Thus the line passing through England, for instance, is marked 25°, and that passing north-west of the British Islands 30°. At places under those lines, the needle points to a north 25° and 30° west of the true north. On the space intervening between these lines, including Scotland and Ireland, a correction, varying from 0° to 5°, must be made according as the

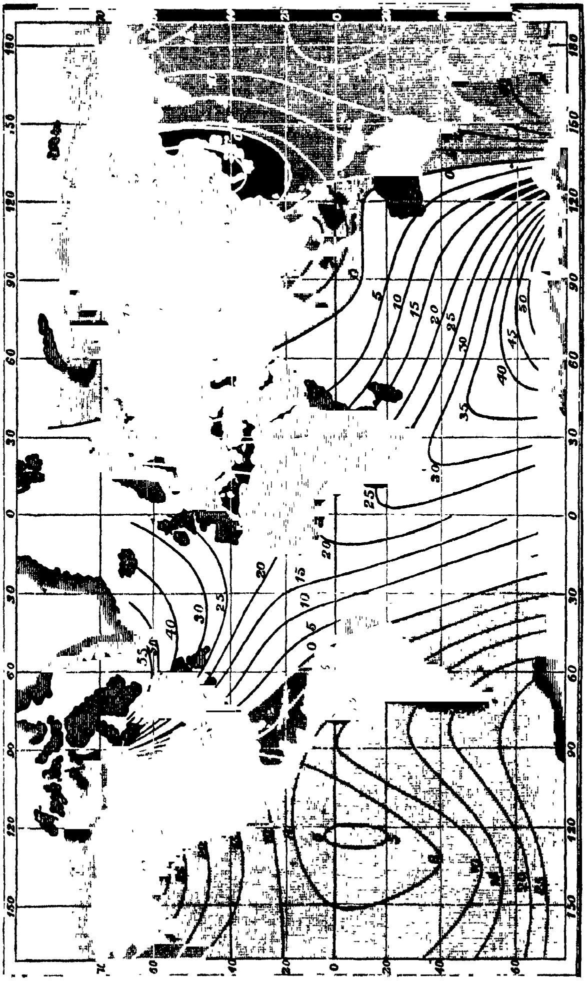

180
150
120
90
60
30
0
30
60
90
120
150
180
70
60
40
20
0
20
40
60
0
5
10
15
20
25
30
35
40
45
50
55

Fig 24.

station lies more towards the one line than the other. The westerly line of no declination passing northward cuts off the eastern corner of South America, proceeds to North America, which it enters at North Carolina, traverses the continent by Lakes Erie and Huron and the west of Hudson's Bay, and ends in the north of the continent at Boothia. The easterly line of no declination passing southward enters Europe in the north of Russia, crosses the White Sea, the east of Russia, of the Caspian Sea, of Persia, and the Arabian Sea. Then turns eastward, and cutting off the west of Australia, passes southward. The space included between those two lines, and which in the chart is left untinted, constitutes, so to speak, the hemisphere of westerly declination. It includes the east of the two Americas, the Atlantic Ocean, the whole of Europe and Africa, and the west of Asia and Australia. The rest of the earth, which in the chart is tinted, has an easterly declination. There is an elliptic space in Eastern Asia which is left white, having a westerly variation, and forms an exceptional region in the eastern magnetic hemisphere.

It will be seen that the lines converge in the north of North America, and in the south of Australia. So far as experience goes, and so far as the most matter of fact theory (Gauss's) teaches, the convergence in both cases is to a point. The point in North America is the *north magnetic pole*, and that south of Australia is the *south magnetic pole*. At these points, then, all isogonic lines converge, and a compass needle lies indifferently in any position.

According to the same theory, if the isogonic lines were traced on a globe, instead of, as here, on a map in Mercator's projection, they would form irregular circles on the northern and southern hemispheres. Each circle in the north would contain in its circumference the north magnetic and geographical poles, the portion of the circle on the one side of the poles being in the hemisphere of westerly declination, and the other in the easterly. The sum of the angles marked on the two portions would amount to 180°, the larger segment having the smaller angle. The same conformation of circles would be visible at the south pole. These two sets of circles proceeding from both poles, would meet each other at the equatorial regions, and when they began to overlap, would run into each other, forming irregular curves passing through the four poles. This conformation can be traced more particularly on the white part of the chart. In the North and South Atlantic, curves are seen approaching each other, and proceeding from the region of the north and south poles. The last two circles that approach without touching are marked 20°. The circles marked 15° would overlap; but instead of doing so, they run into each other, and form two continuous curves, forming together somewhat like the outline of a sand-glass. The same union, with a less contraction in the middle, is seen in the lines marked 10° and 5°.

The isogonic lines, as seen from the chart, form a somewhat complicated system. This arises from the fact, that we refer the indications of the needle to the geographical poles, which are, so far as we know, arbitrary or extraneous as regards terrestrial magnetism. Duperrey, by drawing what he calls *magnetic meridians and parallels*, draws a system of lines which have much the same conformation with regard to the magnetic poles that the meridians and parallels of latitude have to the geographical poles. A magnetic meridian, according to Duperrey, is the line that would be described by a person setting out, say from the south magnetic pole, and travelling always in the direction of the magnetic north till he reached the north magnetic pole. The magnetic parallels are lines drawn at right angles to the magnetic meridians.

In fig. 25, the isoclinic lines, by the same author and for the same epoch, are given. In the upper part of the chart, which is left white, the north end of the needle dips; and in the lower part, which is tinted, the south end of the needle dips. The amount of dip is marked on each line. Thus, the line passing through the centre of England is marked 70°. A dipping needle, at any place cut by the line, is inclined 70° to the horizon. The line 75° passes to the north of the British Isles. In Ireland and Scotland, therefore, the dipping needle has an inclination greater than 70°, and less than 75°. The line marked 0° is the line of no dip; at any station on it the dipping needle is horizontal. This line is called the *magnetic equator*. It will be

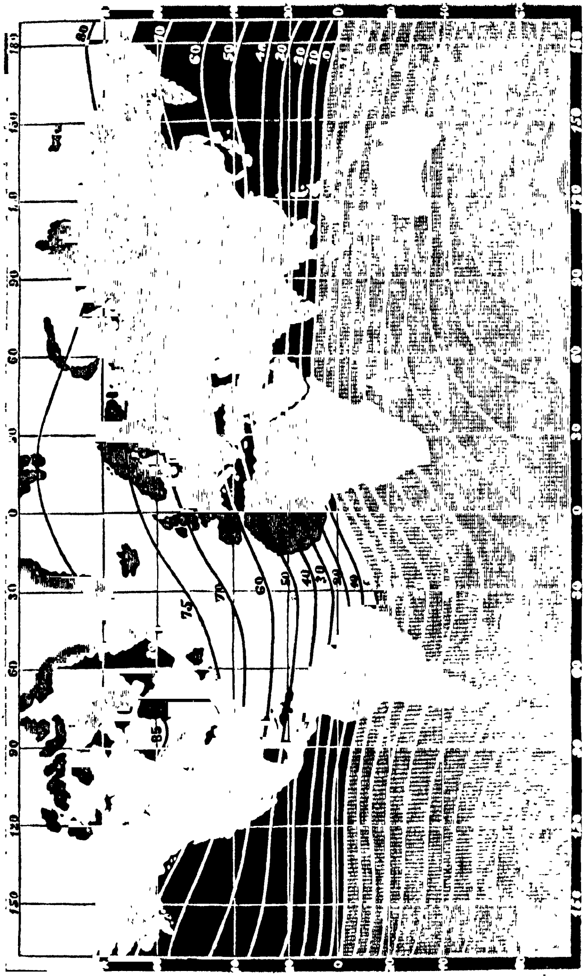

180
150
120
90
60
30
0
30
60
90
120
150
80
70
60
50
40
30
20
10
0
75
70
60
50
40
30
20
10
85

Fig. 25.

seen that it is not coincident with the geographical equator; it is not even a great circle of the earth, but is an irregular curve cutting the equator in two points, one near the west coast of Africa, and the other in the middle of the Pacific Ocean. The points on the earth's surface where the dipping needle stands vertical, and where, in consequence, as before-mentioned, the compass needle lies in any direction, are called the magnetic poles. The north magnetic pole was found in Boothia Felix by Captain Ross at 70° 5′ N. lat. and 263° 14′ E. long. According to Gauss's calculation, it should have been at the time (1831) some 3° north of this point. From observations made at Hobart Town, the nearest station to it, the south magnetic pole should lie 66° S. lat. and 146° E. long. These points are not diametrically opposite each other as the geographical poles. If the lines of equal dip were drawn on a globe, they would form round the magnetic poles a system of irregular circles, somewhat resembling that of the parallels of latitude round the poles of the earth.

We do not add an isodynamical chart as it would engross too much space. Colonel Sabine's Dynamical Chart, along with the isogonic and isoclinic charts, will be found fully engraved and explained in Johnston's *Physical Atlas* (new edition). From this chart we learn that the magnetic intensity is least in the vicinity of the magnetic equator, and increases as we approach the magnetic poles. The lines of equal intensity, though running much in the same direction as the lines of equal dip, are neither coincident nor parallel with them. The line of least intensity, itself not an isodynamic line, runs nearly parallel to the magnetic equator, but lies, except in the western half of the Pacific, a few degrees to the south of it. We thus learn that the changes in direction and intensity do not march together. We should fancy that at that point or points on the earth's surface where the dipping needle stood erect, we should be nearest to the centre of free magnetic energy, and that there the force would be greatest; but this is not the case. The point in North America where the intensity is greatest, is situated to the west of Hudson's Bay, some 18° south of the north magnetic pole. But this is not the only point of maximum force in the north magnetic hemisphere. There is another, which was found by Hansteen in 1828, in Northern Siberia, about the longitude 120°. This maximum point is weaker than the American, in the proportion of 100 to 107 (Sabine). According to Gauss, there can only be one maximum point in the southern hemisphere, which is stronger than either of the other two. It lies north-east of the south magnetic pole, and its intensity is 137 (Gauss) compared with 107, that of the principal northern centre. At none of those points does the dipping-needle stand erect. This want of coincidence of the points of vertical dip and of maximum intensity has led to some confusion in the use of the term magnetic pole; some writers meaning by it a point of vertical dip, and others a point of maximum intensity. In adopting the former definition, we are only adhering to the popular meaning of the word, and to the opinion of Gauss, perhaps the greatest authority on the subject. Some of the best English authorities, however, attach to it the latter meaning.

Although the total intensity increases as we go northward or southward from the line of least intensity, the horizontal intensity diminishes. This arises from the fact that the horizontal intensity depends on the dip; the greater the dip the less the horizontal intensity (17). Hence, the compass-needle, which is affected alone by the horizontal intensity, oscillates more sluggishly as we leave the line of least intensity. A dipping-needle, for instance, oscillates faster at London than at Calcutta, because the total intensity which affects it is greater at London than at Calcutta, but with a compass-needle it is the reverse, from the horizontal intensity being greater at the latter than at the former station.

20. *Variations of the Needle.*—The magnetic elements do not remain constant in the same place, but are subject to continual though small variations. These are regular and irregular. Under regular variations are included *secular*, *annual*, and *diurnal* variations. The secular variations take centuries for their completion. The following list of the declination and dip at London in different years

will give an idea of the secular variations for these elements:

Year.	Declination.	Year.	Inclination.
1576, . .	11° 15′ easterly.	1720, .	74° 42′.
1657—1662,	0° 0′, no declination.	1780, .	72° 8′.
1760, . .	19° 30′ westerly.	1800, . .	70° 35′.
1815, .	24° 27′ 18″ westerly. Maximum.	1830, .	69° 38′.
1850, . .	22° 29′ 30″ westerly.	1850, . .	68° 48′.
1865, Jan. 1, at Kew,	21° 6′.	1865, Jan. 1, at Kew,	68° 9′.

From these observations it will be seen that in 1576, when the earliest reliable measurement of the declination was made, it was 11° 15′ easterly. This divergence from the true north diminished till 1657—1662, when it pointed to the true north. It then varied westward till 1815, when it stood furthest from the true north. Since then the needle has been veering eastward, and coming nearer to the north. At present, the annual decrease of declination at Kew is 8′. At this rate it would take rather more than eighty-four years before the compass-needle shifts through a whole point. From the observations of the dip, we find that it has been gradually decreasing for the last one hundred and fifty years. The annual decrease of dip is at present about 2′·6. From the time observations have been taken of the declination and dip until now, we are far from having completed a cycle of change in either, and it is as mere matter of speculation how long that may take. The magnetic history of London does not apply to other places; each place, so far as has been ascertained, having a magnetic history of its own. Thus, in Paris, the time of no declination was 1669; and of maximum declination, 1814; the latter amounting to 22° 34′ west. Every place, according to Barlow, appears to have its own magnetic pole and equator. Magnetic intensity has been observed for so short a time, that little as yet is known of its secular variation. The total magnetic intensity at Kew, 1st January 1865, was 10·28 British magnetic units, or 4·65 metrical units. At present, the horizontal intensity is increasing in Europe, but that may arise partly from decrease of dip.

The magnetic elements are also subject to changes, which have a yearly and a daily period. In describing these shortly, we shall limit ourselves to the changes affecting declination, as these are of most general interest. The following are the chief particulars of the *annual variation* of declination given by Cassini: From April to July, or from the vernal equinox to the summer solstice, the western declination decreases. From the summer solstice to the vernal equinox, that is, during the other nine months of the year, the declination increases, the needle turning to the west. Its position in May and in October is nearly the same; so that in the winter months, from October to April, the westerly motion is slow. The range of the annual variation at Kew is 58″·85.

The mean *diurnal variation* for Kew is shewn in fig. 26 (kindly furnished by Mr G. M. Whipple of the Observatory). This irregular line indicates the course of the north end of the needle. A rise of this line indicates a change of the north end to the east, a fall a change to the west. The interval between two horizontal lines corresponds to a deflection of the needle 1′ to the east, and a fall 1′ to the west. The line marked *o* is the magnetic meridian, or the mean daily position of the needle. The interval between two upright lines corresponds to an hour. The course begins at twelve at night, and ends at twelve the following night. At twelve at night, the magnet is 1⅛′ east of the mean

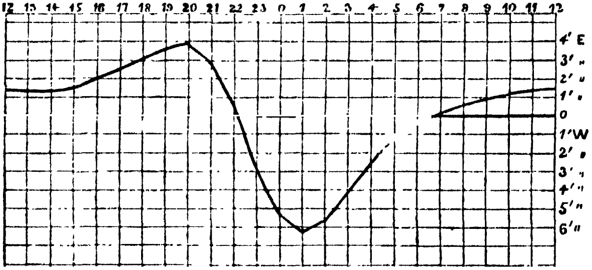


Fig. 26.

position, and continues nearly in the same position, with only a slight westerly deviation, till fifteen hours (three in the morning), when it veers eastward. At twenty hours (eight in the morning) it reaches its furthest east point. From eight in the morning till one in the afternoon, it makes a sweep of 10′ towards the west, and then stands about 6′ to the west of the mean. After one, it goes westward till midnight, when it again begins the same course. The needle stands in its mean position a little after ten in the morning, and a little before seven in the evening. The course here described is the course for the year. But the diurnal range is different in different months. In May, for instance, the average range between the extreme points is 12′, which is the maximum range for the year; and in December, when it is a minimum, it is only 5′ 28″. The diurnal changes here described for Kew are much the same all over the north magnetic hemisphere. The amount, however, is different. Near the magnetic equator the diurnal variation is little or nothing, and it increases as we go northward. Captain Duperrey states that at or near the magnetic equator, the north point of the needle in the morning shifts slightly east or west of the mean, according as the sun passes south or north of the station. In the southern magnetic hemisphere the daily motions of the needle take place much in the same way as in the northern hemisphere, only the south pole takes the place of the north pole, and the direction of the deflections is reversed. The correspondence, and at the same time opposition, of the southern hemisphere is also shewn from the time of maximum and minimum range. When the sun is in the northern signs of the zodiac, the range is a maximum in the northern, and a minimum in the southern hemisphere; and when the sun is in the southern signs, the reverse takes place. The diurnal variation is so small, that the ordinary compass-needle is not delicate enough to shew it.

The *irregular variations* are those which break in upon the regular march of the diurnal variation without in the main altering it. Instead, for instance, of the needle steadily going westward from 8 A.M. to 1 P.M., as shewn in fig. 26, it makes, when affected by irregular variation, deflections eastward as well as westward, although it in the main moves westward. So that the line between these hours, instead of being comparatively straight, would be an irregular zigzag. These disturbances of the mean course are sometimes considerable, amounting even to one or two degrees in extreme cases. On some days the mean diurnal course is much disturbed, on others very little; but it is never quite free from them. It has been found that places of the same longitude have similar disturbances at the same time; that those on opposite sides of the globe, or differing by 180° of longitude, have disturbances equal in amount but opposite in direction; and that those situated 90° west or east of the disturbed regions have little or no disturbance. The appearance of auroras is invariably accompanied by magnetic irregularities, and their effect extends far beyond the regions where they are visible. Earthquakes and volcanic eruptions have also a marked effect in this way. Humboldt gave the name of *Magnetic Storms* to these irregular disturbances. Sabine has found that the frequency of magnetic storms is greatest every ten years at the same time that the spots on the sun are most numerous.

21. *Theories of Terrestrial Magnetism.*—The earliest theory was that suggested by Gilbert, in which it is supposed that a magnet in the middle of the earth extended from one magnetic pole to the other. On this supposition, the general phenomena of terrestrial magnetism may be accounted for—a needle, both by declination and dip, must point to the poles. This must always remain, from its simplicity, the popular theory on the subject. In consistency with his theory, Gilbert considered the north pole of the magnet to be a south pole, as he took the north pole of the earth for his standard north pole. If this theory were correct, the magnetic equator would be a great circle of the earth, and the magnetic poles would be 90° from it, which is far from the case. It is only a rough approximation to a just theory.

Halley endeavoured to supplement Gilbert's theory, by supposing two magnets of unequal strength crossing each other at the earth's centre to be the cause of terrestrial magnetism. The theory of the two magnets or four poles was ably defended by Hansteen.

Barlow considered that the earth acted on the needle as if currents of electricity traversed it from east to west. He imitated its action by wrapping a wire in parallel coils round a wooden globe, and causing a galvanic current to pass through it. Each turn of the wire represented a magnetic parallel, and the two ends of the coil the magnetic poles; and to complete the analogy, the globe was movable on an axis, which stood in the same relation to the ends of the coil as the astronomical to the magnetic poles of the earth. When a small needle was placed on the globe, its declination and dip bore a striking resemblance to those of a needle similarly situated on the earth's surface. The objection to this theory is the difficulty of accounting for the origin of such currents in the earth. To meet this, some suppose the earth to be a huge thermo-electric pile; as the heat of the sun falls on one side of it, currents are there generated which travel round the globe. But how, again, it may be asked, are the conditions of thermo-electricity implemented by the materials of the earth? This question still remains to be answered. The close connection between temperature and magnetism is shewn by the diurnal variation of declination, the epochs of which closely correspond with those of the daily temperature, and by the fact that the isodynamic and isothermal lines manifest a marked correspondence. Sir David Brewster has also shewn that there are two centres of maximum cold in the northern hemisphere, which are situated near to the two intensity poles.

Gauss did not start from any simple supposition of one or two magnets giving rise to the magnetism of the earth, nor did he assert or deny its electro origin. Considering the whole earth as magnetic, he aimed at determining how it must act as a whole at the different points on its surface. In order to make the equations he obtained theoretically in this attempt express the distribution on the earth, the magnetic elements of eight stations at a sufficient distance from each other on the earth's surface had to be ascertained and substituted in these equations. This done, from the longitude and latitude of any station he considered himself prepared to deduce its magnetic elements. The magnetic charts which he sketched, though founded on the imperfect observations to which he had access, are singularly in keeping with fact, and go far to establish the correctness of his reasonings.

The secular variations are as yet wholly unaccounted for. The cause of the diurnal variation is universally attributed to the sun. Secchi, who carefully studied the diurnal variation of the needle, considers that the sun, so far as they are concerned, acts upon the earth as a powerful magnet at a distance.

Diamagnetism.

22. Dr Faraday was the first (1845) to shew that all bodies are more or less affected by magnetic influence, and his beautiful researches on the subject have opened up a new field in the domain of science. He found that the magnetism of bodies was manifested in two ways—either in being attracted by the magnet, as iron; or in being repelled, like bismuth. When a needle or slender rod of iron is suspended between the poles of a magnet, as in fig. 27, being attracted by them, it takes up a position of rest on the line *ab*, joining the two poles. When a substance behaves itself in this manner, it is said by Faraday to be *paramagnetic*, and to place itself *axially*, *ab* being the axis. A rod of bismuth, on the other hand, being repelled by the poles of the magnet, comes to rest in the line *cd*, at right angles to *ab*. Bismuth, and the like substances, he calls *diamagnetic*, and they are said to place themselves *equatorially*, *cd* being the equator. These terms, being both definite and graphic, have been universally adopted. Magnetic is the term used by Faraday to indicate magnetism

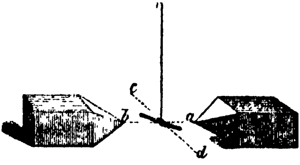


Fig. 27.

of either sort, although in general language it is understood to refer to paramagnetic bodies, such as iron, &c. Paramagnetic bodies, then, are those which manifest the same properties with regard to the magnet that iron does; and diamagnetic bodies are those which, like bismuth, shew opposite but corresponding properties; so that in circumstances where paramagnetic bodies place themselves axially, diamagnetic bodies place themselves equatorially; and where the former are attracted, the latter are repelled, and *vice versâ.* A paramagnetic, therefore, not in the elongated form, but in a compact shape, such as a ball or cube, is attracted by either pole of the magnet, when suspended near it; a ball or cube of a diamagnetic, on the other hand, experiences, when so placed, repulsion.

The paramagnetism of iron, nickel, and cobalt becomes manifest in the presence of magnets of ordinary power; but the magnetism of most other substances is so feeble as to be developed only under the influence of the strongest magnets. Electro-magnets are selected for investigations on the magnetism of bodies, as they can be made of a strength far outrivalling that of permanent magnets. Fig. 28 represents an electro-magnet which may be employed for this purpose. The soft iron horseshoe PPP, enveloped towards its extremities in the coils of insulated copper-wire *cc*, which communicate with a galvanic battery by the wires *w*, is fixed in an upright wooden frame. The ends or poles of the magnet rise slightly above the table or board which forms the upper part of the frame. In order conveniently to suspend substances between the poles, and to

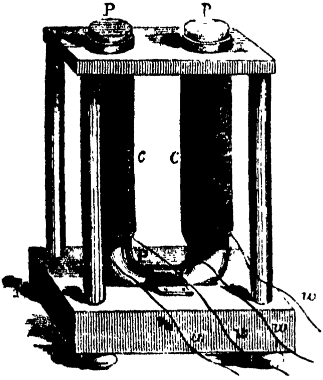


Fig. 28.

protect them while under observation from currents of air, a glass frame of simple construction, fig. 29, is made to fit the table. The upper plate of the frame admits a wooden ring, into which an upright glass tube is fitted. The thread by which the needle is suspended is wound round a slender movable bobbin at the top, so that it can be elevated or lowered to the proper position. To modify and direct the action of the magnet, two pieces of soft iron (fig. 27) are made to rest on the end faces; these are pointed at one extremity, and flat at the other, so that the force of the magnet may be concentrated in the points, when they are turned towards each other; or diffused over the opposite flat surface, when their position is reversed.

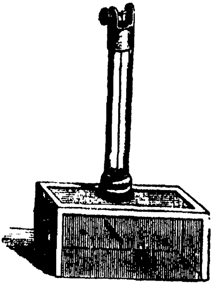


Fig. 29.

To observe the effect of the magnet on liquids, Faraday placed them in long tubes of very thin glass, and suspended them as in the case of solid needles. It was found that some arranged themselves axially, and others equatorially. The attraction and repulsion that liquids experience in the presence of the magnet has been prettily shewn by Plucker. A large drop of liquid is placed in a watch-glass (figs. 30, 31), and laid upon two poles of the shape shewn in the figures. If the liquid be paramagnetic, the surface becomes depressed at the interval between the poles, and heaped up over the extreme edges of them (fig. 30). A diamagnetic liquid, on the other hand, shews a depression at each edge of the poles, and a heaping up at the centre (fig. 31).

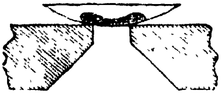


Fig. 30.

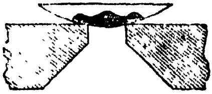


Fig. 31.

The magnetic nature of flames and gases has been also studied. When the flame of a candle is brought between the poles of a magnet, it is repelled by them, and thrown out horizontally into an equatorial position. To ascertain the magnetism of gases, Faraday inflated soap-bubbles with them, and their para- or dia- magnetism was exhibited by their being attracted or repelled by the poles. He ascertained the same by causing the gases to flow out from glass tubes in the presence of the poles, when the peculiar magnetism of the gas was shewn by its choosing an axial or equatorial means of egress.

The following list gives the kind of magnetism displayed by the more common substances in the order of their powers:

Paramagnetic.—Iron, nickel, cobalt, manganese, chromium, titanium, palladium, paper, sealing-wax, peroxide of lead, plumbago, red-lead, sulphate of zinc, shell-lac, vermilion, charcoal, proto and per salts of iron, salts of manganese, oxygen, air.

Diamagnetic.—Bismuth, antimony, zinc, tin, cadmium, sodium, mercury, lead, silver, copper, gold, arsenic, uranium, tungsten, rock-crystal, mineral acids, alum, glass, litharge, nitre, phosphorus, sulphur, resin, water, alcohol, ether, sugar, starch, wood, bread, leather, caoutchouc, hydrogen, carbonic acid, coal-gas, nitrogen.

The nature of the medium in which the body under examination moves, exerts a powerful influence on the nature and amount of the magnetism it exhibits; thus, if a glass tube be filled with a solution of the proto-sulphate of iron, and suspended between the poles, it will place itself axially. It will do the same if made to move in water, or a solution more dilute of the proto-sulphate of iron. It will be indifferent in a solution of the same strength, but it will place itself equatorially in a stronger solution. Thus, the same substance may appear paramagnetic, indifferent, or diamagnetic, according to the nature of the medium in which it moves. As a general rule, a body shews itself paramagnetic towards one less paramagnetic than itself, indifferent towards one equally magnetic, and diamagnetic towards one more paramagnetic than itself The same takes place, *mutatis mutandis*, with diamagnetic substances. This has given rise to the theory, that there is no such thing as diamagnetism *per se*, and that bodies are diamagnetic only in media of greater paramagnetic power than their own. This view of the case is, however, rendered highly improbable from the fact, that diamagnetism is exhibited as decidedly in a vacuum as in any medium, and a vacuum cannot be supposed to possess magnetic properties of either kind.

Chronology of Magnetism.

23. The property of the loadstone to attract iron appears to have been the only fact in the science of magnetism known to the ancients. The compass is a comparatively modern discovery; it was certainly known in Europe in the 12th century, the first reference to it being made in a manuscript poem by Guyot de Provins, now in the national library of France. The Chinese, according to some, were acquainted with it as early as the 4th century. The discovery of the change in declination at different places is generally attributed to Columbus, and was one of the many important observations of his memorable voyage across the Atlantic. Robert Norman, an instrument-maker in London, first discovered the dip of the needle in 1576. He was led to it by finding that needles nicely balanced before magnetisation had to be slightly loaded on the south end, to keep them horizontal after being magnetised. The first really important contribution to magnetism as a science, was the *Tractatus de Magnete* by Dr Gilbert of Colchester, physician to Queen Elizabeth. It was published in 1600. He first used the word poles with reference to magnets, and gave the first theory of terrestrial magnetism, viz., that of the single magnet. Halley, the astronomer-royal, published his theory of the four poles in 1683. In 1688 and 1689, at the expense of government, he made two magnetic voyages, the results of which he embodied in his charts of the lines of equal declination, published in 1701, which were the first

magnetic charts ever published. In 1722 the diurnal variation was discovered by Graham, the celebrated instrument-maker of London. About the middle of the 18th century, armatures began to be used, and various new processes of magnetisation were found out. Knight invented divided touch, which was afterwards improved by Duhamel (9); and Mitchell double touch, afterwards improved by Epinus (9). Brugman, in 1778, discovered that cobalt was attracted and that bismuth was repelled by the magnet. Coulomb (1789) discovered the law of the distribution of magnetism on a magnetic bar, and the law of magnetic attractions and repulsions. The first inclination chart was published by Wilke, at Stockholm, 1768. Humboldt inaugurated the present system of careful observations of terrestrial magnetism by taking comparative measurements of the magnetic elements at Peru and Paris (1799—1803). Hansteen's work on the *Magnetism of the Earth* (21) was published at Christiania, 1817; in 1826 he published the first isodynamic charts. Barlow, 1831, suggested the electric origin of terrestrial magnetism (21); and 1833, introduced correcting plates of soft iron for ships. In 1831, Captain Ross came upon the north magnetic pole. In 1835, stations were established throughout Europe, and the observations were published by Gauss and Weber, 1836. Gauss (1833—1840) perfected his theory. In 1837, Colonel Sabine published an isodynamical chart of the whole globe. Diamagnetism was discovered by Faraday, 1845. Observations were made (1840—1854) at stations throughout the British Empire by British officers, under the direction of Colonel Sabine. In 1855, Tyndall shewed that a diamagnetic body assumed a polarity similar in action but transverse to that of a magnetic body when under the action of magnetic force.

FRICTIONAL OR STATICAL ELECTRICITY.

First Principles.

24. *Electricity of two kinds, Positive and Negative.*—The first principles of electricity are illustrated by the *electric pendulum* (fig. 32). A glass tube bent at right angles, so as to project horizontally, is placed on a convenient stand. On the hook in which its upper end terminates, a cocoon thread is hung, to the end of which a pith-ball is attached. Glass and silk, as will be afterwards mentioned, do not conduct electricity, so that whatever electricity is communicated to the ball remains in it. If a tube of glass be rubbed by a dry silk handkerchief, and brought near the ball, the ball is at first briskly attracted, and then as briskly repelled; and if the tube be then moved towards it, it moves off, keeping at the same distance from it. The ball being so affected, or charged, as it is called, a rod of shell-lac or of sealing-wax, after being rubbed with flannel, attracts it, if possible, more briskly than before, and again sends it off exactly as the glass had done. If the glass tube be now again taken up and rubbed a second time, if necessary, the ball will act towards it as it did towards the sealing-wax. The same series of attractions and repulsions would have taken place if we had begun with the sealing-wax instead of the glass tube. We interpret this experiment in the following way. When glass is rubbed with silk, it becomes invested with a peculiar property, by virtue of which it is enabled to attract

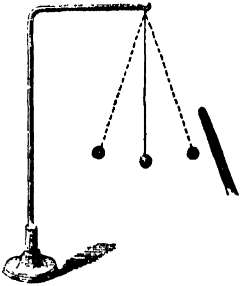


Fig. 32.

a pith-ball or any other light substance; and after contact has communicated this property to the ball or other matter, repulsion takes place between them. In consequence of the ball being suspended by an insulating thread, it retains the property of rubbed glass thus given it; and although then repelled by a body having the same property, it is powerfully attracted by rubbed sealing-wax. After contact again takes place, and the property of rubbed sealing-wax has replaced that of rubbed glass in the ball, the two similarly affected bodies again repel, and the same series of attractions and repulsions will continue if we present the glass and the wax alternately to the ball. These properties or affections, developed on the glass and wax, by friction, receive the name of electricities; the electricity of the glass being called *vitreous*, and that of the sealing-wax *resinous*, glass and resin being the type substances on which they are produced. For vitreous, *positive*, and for resinous, *negative*, are now almost universally substituted; and although these terms are meaningless as applied to two similar affections of matter, they have the advantage of being definite, and of having no reference to the source whence the electricity originates. They admit, moreover, of a very convenient contraction, viz., the algebraic + for *positive*, and − for *negative*; and when written in this way, their relative opposition, so to speak, is graphically shewn. Throughout this work, we shall use the contraction + E for positive electricity, and − E for negative electricity. We are taught by the above experiment, *that bodies electrified either positively or negatively, attract neutral bodies and bodies affected with electricity of an opposite name to their own, but repel those affected with electricity of the same name; and that electricity can be communicated from one body to another by contact.* Contact is not the only way in which one body communicates the like electricity to another. We find, when we deal with larger bodies than the pith-ball of the experiment, and sometimes even with it, that the passage of a *spark* between two bodies without contact communicates the electricity of the one to the other.

25. *Both Electricities produced together.*—The part played by the rubbers in the above experiment must not be overlooked.

The silk handkerchief employed to rub the glass assumes the resinous or – electric state, and the flannel rubber of the sealing-wax the vitreous or +. This cannot, however, be clearly shewn, as the experiment is performed, for the rubbers are in each case tightly embraced by the hand, which carries off their peculiar electricity, so that they give feeble, if any, evidence of electrical excitement. As the rods are held only by their extremities, the electricities of the untouched portions suffer almost no diminution. If vulcanised india-rubber cloth, however, be used instead of the silk handkerchief, the rubbing side of the cloth shews – E. The different electricities of the rubbing surfaces are best shewn when the rubbers as well as the rubbed surfaces are insulated. When two similar discs —one of glass, the other brass covered with silk—held by insulating handles, are rubbed together: so long as they are kept touching, no electricity is shewn, for the opposite electricities neutralise each other; but when they are separated, the former shews +, the latter – E. The negative and positive conductors of the electric machine illustrate the same principle. From the most careful observations attending the production of electricity, we are led to conclude that *when one electricity is produced, as much of the opposite electricity is produced.*

The relative nature of the rubbing and rubbed surfaces determines the kind of electricity which each assumes. Thus, if glass be rubbed by a cat's fur instead of silk, its electricity is – instead of +. In the following list, each body, when rubbed by any one preceding it, is negatively electrified; by any one succeeding it, positively: cats' fur, smooth glass, linen, feathers, wood, paper, silk, shell-lac, ground glass. When two pieces of the same material are rubbed together, the colder or smoother becomes positively excited. Metal filings rubbing against a plate of the same metal determine – E in themselves, and + E in the plate. When a white silk ribbon is rubbed by a black one of the same texture, the white one becomes +. A plate of glass becomes + when a stream of air is directed against it from a pair of bellows. The friction caused by steam of high tension issuing from a narrow pipe develops electricities in the steam and pipe which depend on the material of the latter. This fact has been turned to advantage by Armstrong in the construction of a boiler electric-machine of immense power.

26. *Sources of Electricity.*—There are other means of developing electricity of the same nature as that obtained by friction, besides friction itself. In general, everything that tends to disturb the molecular condition of bodies tends to produce electricity. *Cleavage, pressure,* and *change of temperature,* more especially in crystalline minerals, are frequently attended with the development of electricity.—The electricity of cleavage is shewn by rapidly cleaving a plate of mica, when one of the divided faces shews + E, the other – E. A feeble phosphorescence also marks the separation when made in the dark. Several other minerals possess the same property. The light that accompanies the breaking of loaf-sugar and sugar-candy in the dark is generally attributed to the electricity of cleavage.—Haüy found that when a piece of calc spar is pressed between the fingers, it becomes positively electrified, and remains so for days together. Fluor spar, topaz, mica, arragonite, quartz, and other minerals, assume one or other electricity when pressed. When two discs, one of cork, the other of caoutchouc, are pressed together by insulating handles, on separation the former is found to be +, the latter –. A slice of cork and a slice of orange observe the same relation in similar circumstances. When in the latter case the separation is suddenly made, we obtain a greater effect than when it is made slowly, from which we learn that conducting surfaces when pressed together shew no excitement, probably from the recombination of both electricities at the instant of their production.—Tourmaline offers the most remarkable illustration of the electricity got by change of temperature. When a crystal of this mineral is heated, it shews at each end of its principal axis a different electricity. If it be divided when thus excited, each of the halves has an electricity at each end like the whole. It thus manifests an electric polarity, like the magnetic polarity of the magnet. When the heating ceases, for an instant it loses polarity, and then as it cools it assumes the opposite polarity to that it had before. Below 50° F., and above 302° F.,

tourmaline seldom shews electric properties. Topaz, boracite, and several other minerals, resemble tourmaline in their action under heat. The electricity thus developed by heat is sometimes called *pyro-electricity.*—There are other sources of electricity, of which we shall afterwards treat, such as chemical action, motion of magnets, heating of different metals at their junction, &c.; but these give current electricity, while friction, cleavage, &c., give statical electricity whose properties are best studied when insulated or at rest.

27. *Conductors and Non-conductors* (Ger. *Leiter, Nicht-leiter*).—If a rod of metal be made to touch the prime conductor of an electrical machine immediately after the plate has ceased to rotate, every trace of electricity instantly disappears. But if the same were done with a rod of shell-lac, little or no diminution would be perceptible in the electrical excitement of the conductor. The metal in this case leads away the electricity into the body of the experimenter, and thence into the ground, where it becomes lost, and it receives in consequence the name of a conductor. The shell-lac, for the opposite reason, is called a non-conductor. Different substances are found to possess the power of conducting electricity in very different degrees. The following series classifies the more common substances according to their conducting powers, beginning with the best, and ending with the worst conductors. Conductors—The metals, graphite, sea-water, spring-water, rain-water. Semi-conductors—Alcohol and ether, dry wood, marble, paper, straw, ice at 32° F. Non-conductors—Dry metallic oxides, fatty oils, ice at −13° F., phosphorus, lime, chalk, camphor, porcelain, leather, dry paper, feathers, hair, wool, silk, gems, glass, agate, wax, sulphur, resin, amber, gutta-percha, caoutchouc, shell-lac, ebonite, water-vapour as a dry gas, dry gases.

The arrangement into conductors, semi-conductors, and non-conductors is made with reference to frictional electricity, or electricity of a high tension. The substances which are semi-conductors for frictional electricity are found to be almost, if not altogether, non-conducting for the electricity of the galvanic battery, which is too feeble to force a passage through them. The metals, which appear to be all nearly alike conducting for frictional electricity, offer widely differing resistances to the transmission of the galvanic current. Their relative conducting powers are afterwards given under GALVANISM. An increase of temperature has in the metals the effect of lessening the conducting power, whilst in almost all other substances it has an opposite effect. Glass becomes conducting at a red heat, and so do wax, sulphur, amber, and shell-lac, when fused.

Insulation.—When a conductor is placed on non-conducting supports, so as to prevent the electricity communicated to it from passing into the ground, it is said to be *insulated*. The usual insulating material employed in the construction of electrical apparatus is glass, which is hard, durable, and easily worked; and could its surface be kept dry, it would be one of the best non-conductors. In frosty and very dry weather, glass insulates well; but at all other times it becomes coated with a thin, scarcely visible, layer of moisture, which very considerably impairs its insulating power. In order to insure dryness, it is necessary to heat electric apparatus before use. Water-vapour, in the form of an elastic gas, is non-conducting, and when it can be kept from condensing on the glass, it does not in that state affect the insulating power of the air. The deposition of moisture is much lessened by coating the glass with shell-lac, which is done by painting the glass when hot with shell-lac varnish. Green glass, which contains no lead, is better adapted for the construction of electric apparatus than flint glass, and does not attract moisture to the same extent. Ebonite, a rigid preparation of vulcanised india-rubber, which has come much into use of late, is much superior to glass as an insulator. It is of this substance that india-rubber combs are made, which in dry and frosty weather make the hair crackle with electricity. With the best insulators, and with dry air, it is not possible to maintain undiminished the charge which a body receives. There is invariably a loss, arising chiefly from the particles of air or dust becoming charged, and carrying off the charge, and partly, perhaps, from the insulators, even the best of them, being imperfect non-conductors. In all exact experiments it is necessary to ascertain the rate at which the charge diminishes, and to take it into account in estimating results.

Electrics and Non-electrics (Fr. *idioélectriques, anélectriques*). —The term *electrics* is applied to those substances which, when held in the hands and rubbed, become electric; and *non-electrics*, to those which do not. The distinction is almost an unnecessary one, for almost all bodies when rubbed become electric. In the case of conductors, the electricity is no sooner excited than it is conveyed by the body to the ground; while in the case of non-conductors, from want of conduction, it remains on their surface. When a metal rod is rubbed with a silk handkerchief, no electricity is shewn by it if it is held in the hand; but if it be held by a handle of glass, it becomes electric. The hand conveys the electricity of the rod to the ground in the first case, but the glass, insulating the rod in the second, prevents this discharge. The rod is truly an electric in both cases; non-electric is a term which, strictly speaking, is applicable to very few, if any, substances.

Statical Induction.

28. *Induction* (Fr. *influence*, Ger. *Vertheilung*).—Electricity has the power of inducing the bodies in its neighbourhood to assume a peculiar electrical condition; this is exhibited in the following simple way: A brass cylinder, rounded at both ends (fig. 33), is insulated on a glass pillar. Two pith-balls, hung by cotton threads, are attached at either extremity. When an insulated ball charged with + E is placed within a few inches of the end of the cylinder, the balls at each end diverge, shewing that each pair is charged with the same electricity. When the charged ball is withdrawn, the balls hang down as before, so that the electrical excitement of the cylinder is merely temporary, and dependent

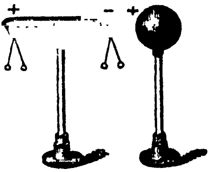


Fig. 33.

on the proximity of the charged ball. If, while the balls are apart, a *proof plane* (Fr. *plan d'épreuve;* Ger. *Probescheibchen*) consisting of a small disc of gilt paper, insulated at the end of a glass rod (fig. 34), be made to touch the end next the charged ball, and then transferred to an electrometer, the electricity is found to be – ; if the same be done at the other end, it is +. The nearer end of the cylinder is thus induced by the + E of the charged ball to assume the negative electric state ; and as no – E can be excited without as much + E, we find the other end positively electrified to the same extent. That the induced electricities are equal in amount, is proved by the fact that they neutralise each other when the ball is withdrawn. If the cylinder were made up of two parts, each supported by a glass leg, the two electricities might be insulated on withdrawing the parts from each other in the presence of the charged body, the one being +, and the other –. The neutral line between the two electricities is found to be nearer to the end next the ball, and to shift nearer to that end as the ball approaches. The action of the electricity of the charged ball inducing in the cylinder this peculiar electrical condition is called *induction,* and the cylinder in this state is said to be *polarised;* that is, to have its poles or ends like a magnet, each having its similar but relatively opposite force.

Fig. 34.

The + E of the further half of the cylinder (fig. 33) is as

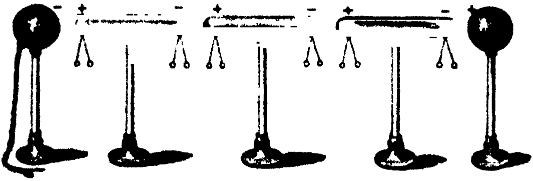


Fig. 35.

free and insulated as if no – E existed on the other half. This is shewn by placing a cylinder near the first, forming a continuation of it, as it were, without touching, when the second cylinder, under the induction of the + E of the first, is thrown into the same state as the first. This second can induce the same state in a third (fig. 35), and so on. As the charged ball is withdrawn, the whole series return to their natural condition without being in any way permanently affected. The moment, however, it is again brought near, each cylinder becomes again polarised, and there is manifested at the further termination of the last a + E, which exerts the same influence on the ball connected with the ground as if a portion of the electricity of the ball had been actually communicated or transferred to it.

From the position of *both electricities* in induction, it is manifest that they *observe the same attractions and repulsions as the bodies affected by them.* Induction throws light on electric attraction. The pith-ball of the electric pendulum (fig. 32) is in the neighbourhood of the excited glass in the same polarised condition as the cylinder (fig. 33). The side of it next the glass is − by induction, and it is not, as at first supposed, the + glass attracting the neutral ball, but the + glass attracting the side of the ball in an opposite electric state to itself. Owing to the greater distance of the + side of the ball, the repulsion of the like electricities is less than the attraction of the unlike electricities. Attraction thus always occurs between bodies affected by opposite electricities.

The amount of the electricity induced by an electrified body on surrounding conductors is equal and opposite to that of the inducing body. Faraday proved this by the following beautiful experiment. He insulated an ice pail, A (fig. 36), ten and a half inches high and seven inches in diameter, and placed the outside of it in conducting connection with the knob of a gold leaf electroscope, E. A round brass ball, C, suspended by a long dry thread of white silk, was charged with + E, and introduced within the pail. The pail was thus subjected to polarisation, the induced − E being on the inner, and the + E on the outer surface. The divergence of the leaves caused by the induced + E increased as the ball was lowered, until it sunk three inches below the opening, when they remained steadily at the same point. The ball was lowered till it touched the bottom, and communicated its charge to the pail, when the leaves remained in the same state as before. The ball when lifted out was found to be fully discharged, shewing that the + E developed by induction on the outer surface was exactly the same in amount as that of the ball itself. The − E of the inside of the pail being equal to the + E on the outside was therefore equal to the + E of the ball, but opposite in kind. He altered the experiment so as to have four insulated pails inside each other, and the effect on the outmost pail was in no way altered. No force was lost in the transmission from one pail to the other. We may conclude from this experiment that on the walls of a room, or other conductors surrounding the charged body, the total amount of opposite electricity induced is equal in amount to that of the body itself.

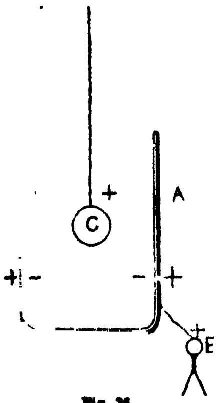


Fig. 36.

29. *Communication of Electricity by Induction.*—If the hand touch the cylinder (fig. 33) when under induction, the pith-balls next the charged ball diverge further than before, and the other two cease to be affected. In this case, electrically speaking, the cylinder is a portion of the ground, for the hand and body are conductors; its dimensions therefore being increased, more − E is developed than before, and the + E is thrown back into the ground, and is lost; or it may be more correct to say that the + E now spread over the earth as well as the cylinder, an infinitely large surface, is infinitely weak or nothing at any point. The − E is kept fixed in the part of the cylinder opposite the ball by the + E of the latter; and when the hand is *first* removed, and *then* the ball, it causes the balls at both ends to diverge permanently. Thus, *when an insulated body is charged by being uninsulated for an instant in the presence of an excited body, or charged, as it is termed,*

inductively, its charge is of the opposite kind to that of the inducing body.

30. *Induction Universal in its Action.*—It would seem, moreover, by a careful study of the action of induction, that when a body is charged by contact or spark, its charge is no less due to it. Let us consider the case of charging the cylinder (fig. 33) by the positively electrified ball. When the ball is brought near to the cylinder, the latter becomes polarised, and the − E is turned towards the ball. When the ball is near enough, by spark or contact, the cylinder is permanently charged with + E. Now this must occur in one of two ways: Either the − E of the cylinder at spark or contact partially neutralises the + E of the ball, and a balance of + E flows over to the cylinder to increase the + charge inductively already there, or an equal amount of both electricities becomes neutralised at contact, and the + E of the cylinder already there is left alone without its negative twin. The latter alternative seems the more likely on many grounds. It seems reasonable to expect that induction, which at the beginning of its action can partially charge the cylinder, can, when complete at contact, fully charge it; and it seems unlikely that the efflux of − E, and the extending of the + E, to which the action at the beginning tends, as is shewn by the shifting of the neutral line towards the point of contact, should be immediately succeeded by an influx of + E, as if the charging of the cylinder had to be done partially by one operation, and fully by an opposite one. Faraday's experiment (fig. 36) shews that no such counterflow takes place. As soon as the ball is low enough in the pail to expend all its inducing force on it, the + E induced on the outside is complete, for the leaves of the electrometer on the ball being lowered further, remain at the same point. The + charge which the pail keeps after contact is not greater than it was before it, for on contact the leaves are not affected. All manifestly that contact effects is a junction or neutralisation of the + E of the ball and the − E induced on the inner surface of the pail, leaving the induced + E of the outside as it was before contact. Similarly, in the case of the cylinder, the charge which it ultimately receives is fully developed in it at contact; contact

merely neutralising the − E, and leaving the induced + E in undisturbed possession of it. The inside of the pail, as shewn by the ball when taken out, is perfectly neutral. The + E which charges the cylinder is equal to the + E of the ball, which is neutralised at contact, for the − E which neutralises the + E of the ball is the twin electricity of the + E of the cylinder. The result of contact is as if a portion of + E had actually been transferred to the cylinder, the loss of the ball being equal to the gain of the cylinder. Induction manifestly has as much to do with charging by contact, or *conductively* as it is termed, as it has with charging by momentary contact with the ground in presence of an excited body, or *inductively*, only the electricities communicated are of opposite names.

But induction leads to discharge as well as charge. Let us discharge the cylinder already charged by contact. On the hand approaching to discharge it, the + E of the cylinder in its turn polarises the hand, causing − E to appear on it, and sending the twin + E into the ground. At contact the + E of the cylinder and the − E of the hand or ground neutralise. It was formerly charged positively by − E leaving it; it is now rendered neutral by an equal amount of + E leaving it.

Lastly, let us consider the condition of the cylinders (fig. 35), if the positively charged ball were discharged through them into the ball connected with the ground. The polarity of the cylinders would be the same as that shewn in the figure. As the inductive action increases, the opposite electricities become more developed at each end. We must place the cylinders at some distance from each other, and from the ball at the other extremity, so as to prevent them touching and acting as one cylinder in connection with the ground. Suppose them so placed that when a spark passes from the ball to the first cylinder, sparks also pass at the other interruptions. When these sparks occur, the ball and the cylinders are finally discharged. Making use of the same reasoning here as we have done above, we cannot conceive of this discharge taking place in any other way than that at each interruption two equal and opposite electricities neutralise each other. The charged ball becomes discharged by the cylinder next it yielding at the spark as much − E as it has of + E; the cylinders act in the same way to each other, discharging opposite electricities at each end; and the + E of the further end of the last cylinder neutralises the − E of the ball connected with the ground. There is here no passage of the electricity of the ball into the ground, but the effect is the same as if it did. Induced electricity is the term applied to electricity that appears on bodies before actual contact or spark. It is the forerunner of charge and discharge, these being, in fact, the crises to which induction tends.

It would thus seem that in whatever way a body acts, whether as giving or receiving a charge, discharging or lying in the path of a discharge, in every case it is by electricities leaving it and becoming neutralised or disappearing by spark or contact. The usual phraseology of electricity supposes the actual passage of the electricities looked upon as fluids, from, into, and through conductors, but the very existence of induction renders such a supposition untenable. Electric terms, like many others, however, in science, though based on a wrong supposition, distinguish quite definitely the phenomena they describe. Moreover, they express what is true in effect, though not in process, and if we look on electricity as a force of which the + and − electricities are merely the manifestations, we may speak of it as entering, leaving, and traversing bodies as one of its manifestations is, according to the usual phraseology, considered to do.

Theoretical Views.

31. *Fluid Theories.*—There are two theories which have played an important part in the history of the science—the two-fluid theory of Dufay and Symmers, and the one-fluid theory of Franklin. According to the former, matter is pervaded with two highly elastic imponderable electric fluids—one, the vitreous; the other, the resinous. These are supposed to repel themselves, but attract each other. Neutral bodies give no evidence of their presence, for they are there

neutralised the one by the other; but when by friction or other operation the fluids are separated, each body observes the attractions and repulsions of the fluid it happens to have. According to the latter, there is only one electric fluid which repels itself, but attracts matter. Friction determines a gain of the fluid to the positive, and a loss to the negative body. Of the two theories, Dufay's is generally preferred, because the perfect similarity of each electricity, separately considered, is better represented by two similar fluids, than by a fluid on the one hand, and matter on the other. The action of induction, as we have just described it, does not seem to favour the idea of electricity being a fluid or fluids. Either theory can give, in the main, a graphic explanation of electric phenomena; but this does not necessarily imply their truth, for any theory which made allowance for the double nature of electric force could not fail to be in some degree satisfactory. It is extremely questionable whether electricity is a fluid at all. It is true that the distribution of electricity on the surfaces of conductors is that of one of the fluids supposed; but to act as a fluid, and to be a fluid, are two very different things, and something more is needed than mere analogy to prove electric fluidity. If such a fluid existed, we might expect to have some traces of its separate existence; but experiment teaches us that electricity is never manifested or transmitted apart from ponderable matter. It is difficult to conceive of fluids of the nature supposed. They are, in fact, quite as peculiar as the phenomena which they are intended to explain; still, the science of electricity is very much indebted to the supposition of its fluidity. It has served to lessen the abstractions of the science, and to simplify the comprehension of phenomena, much in the same way that the balls of an abacus, though not numbers, facilitate calculation by being dealt with as such.

32. *Faraday's Theory of Induction.*—Faraday has propounded a theory of electric action by induction, which, though it does not profess to overturn the other theories, in effect does so, by leaving room for the assumption that electricity need be nothing more than a molecular affection or property of matter. In comprehensiveness it goes far to bind together the varied

and complicated phenomena of electricity in all its conditions into a harmonious whole. We shall therefore give a detailed account of it.

Faraday finds a radical defect in the fluid theories; viz., the leaving out of account of the intervening medium in induction. According to them, an electrified body is a centre from which lines of electric force proceed in all directions in straight lines. Surrounding bodies are more or less affected according as they are more or less near, the air or medium between being in no way concerned in the propagation of the force. The only part played by the air is to keep by its pressure the electric fluid on the electrified body, and prevent it from springing into the bodies presented to it. Faraday considers this view of the function of air to be faulty theoretically, for it seems unlikely that a dense fluid like air can restrain the electric fluid supposed to be infinitely rarer; and he proved, by a series of testing experiments that air has a much more important part to discharge; that it is, in fact, the medium of propagation. We have not space in this small work to quote his experiments, but we shall indicate the general principles of them.

Let A be a body, say positively electrified (fig. 37), PP a metal plate insulated on a glass pillar, connected by a chain with the ground, B a ball provided with an insulating handle. Let us leave meanwhile the series of half-shaded circles or

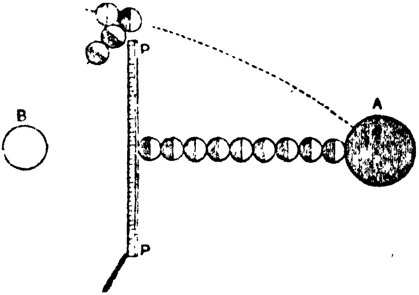


Fig. 37.

of account. Let us suppose that PP being away, B is exposed to the uninterrupted action of A. B in that case becomes polarised, and when touched with the finger it becomes charged with − E (29) the amount of which can be estimated by an electrometer. Let PP now occupy a place in front of B. If, according to the fluid theories, electric force travels in straight lines like the rays from a candle, the plate PP should cast, so to speak, an electric shadow, for the inductive action exerted on it fixes − E on the side next A, and sends the + E to the ground. The back of the plate PP gives not the faintest sign of electricity, so that no action can proceed from it. Faraday found that when B was placed immediately behind the middle of PP it could not be charged. Towards the edge, however, of the plate, and even behind the middle of the plate, when held a little way out, a charge was given it, and in each case negative. At a certain distance behind the middle of the plate the charge reached a maximum, within or without which it fell off. Induction here manifestly turns a corner, or is exerted in curved lines, which cannot be accounted for in any other way than by supposing the air to be the active medium of transmission.

Again, suppose PP insulated, and let B be laid aside, when the plate is touched in the presence of A, it is charged negatively (29), and, as is to be expected, the charge thus given is greater when PP is near A than when it is further from it. If the charge that PP receives at a certain distance be measured when air only intervenes, and again measured when a cake of shell-lac so thick as to fill up nearly the whole intervening space is interposed between A and PP, it will be found that the charge is greater when the shell-lac lies between. The effect is the same as if the plate PP in air had been shifted nearer to A. From this experiment Faraday again concludes that the electric action does not pass through the intervening medium as light through a pane of glass, but that the medium itself is the active channel of communication.

Faraday calls the medium through which induction is propagated as air, shell-lac, &c., the *dielectric*. The relative powers of different substances in facilitating induction are also termed by him *their specific inductive capacities*. The following table by Sir W. S. Harris gives the specific inductive capacities of the more important non-conducting substances, taking that of air as unity: Air, 1·00; resin, 1·77; pitch, 1·80; bees-wax, 1·86; glass, 1·90; sulphur, 1·93; shell-lac, 1·95. All gases, whether simple or compound, have the same inductive capacity, and this is not affected by temperature or density.

Faraday, having proved that induction always has a dielectric, *supposes the particles or molecules of the dielectric to be conductors insulated from each other.* Each particle becomes polarised like the cylinders in fig. 35. The particles in the immediate neighbourhood of the charged body become polarised by its immediate action; they again act on particles next them, and so on. When the polarised particles of air or other dielectric come upon a large insulated conductor, they each exert their polarising influence on it, and the sum of their tiny influences gives its polarity. The conductor itself acts as if it were a huge molecule, and transmits the polarity to the particles beyond it. If we can suppose the ball in fig. 35 surrounded on all sides by a series of insulated polarised cylinders, we have an idea of the condition of the myriads of aërial particles which, according to Faraday, surround it. The different strata of air transmit their polarity to each other without loss, just as the pails do in article 28. The row of half-shaded circles between A and PP gives an idea of the state of one straight row of aërial particles in this condition; those at the edge shew how the induction may turn a corner. The shaded halves are +, the unshaded −, and the half-shaded part of PP neutral.

Faraday generalises further. He considers that *the particles of a conductor are polarised exactly in the same way as those of air or other non-conductor, the only difference being that the particles of a conductor can communicate their electricities to each other much more readily than those of a non-conductor.* The gist of Faraday's theory is to reduce the action that we see on a large scale in insulated conductors to a similar action on the part of molecules, that what we see in the mass really takes place in the molecule. The molecules of matter are thus situated to each other much in the same way as the series of cylinders, fig. 35. If the cylinders are nearly touching, the series may be called conducting; if at a distance from each other, non-conducting; and it may have all degrees of conduction or non-conduction. according to the insulation of the cylinders from each other. Similarly, when the molecules of a body, from some cause or other, are well insulated from each other, the body is non-conducting; when they are scarcely, if at all, insulated, conducting. *The ready communication between contiguous particles constitutes conduction, and the difficult communication non-conduction.*

33. *Electric or inductive force only travels.*—If the view we have taken of induction be correct, the cylinders (fig. 35) discharge the electricity of the charged ball into the ground, not by its electricity passing through them, but by their giving out opposite electricities to the cylinder or ball next them; so each particle, becoming first polarised, discharges by giving off its opposite electricities to the particles next it. Electric force appears first to polarise and then to discharge; first to develop in each particle the two electricities, and then, when powerful enough, to cause these to disappear by contact or something equivalent. Nothing passes from particle to particle but the inductive force, each particle being the seat of the two electricities, and its points of contact of their disappearance, and each possessing the inherent property of being polarised, polarising and discharging as often as the electric force acts on it. The molecules of conductors, from some peculiar condition which Faraday does not attempt to theorise on, are easily polarised, and as easily discharge; those of non-conductors, from an opposite cause, offer considerable resistance to both. In the case of the cylinders the condition of discharge is not altered when they are near each other, and when they are further away, only a greater force is necessary to effect polarisation and discharge in the latter than in the former case. In conductors and non-conductors in the same way the action is precisely alike, only it takes a much greater force to produce polarity and discharge in the latter than in the former. A force, for instance, that would merely produce polarity in a non-conductor, might be more than sufficient to effect discharge in a conductor. According to

Faraday's theory, as interpreted by the view we have taken of induction, conduction begins where induction ends; or rather, perhaps, is the completion of it. Induction deals with the polarising, conduction with the discharging exhibition of electric force.

34. There are numerous evidences of the fact, that *conductors and non-conductors are the same in kind though different in degree.* When the inner and outer coatings of a charged Leyden jar are connected by a long wire, which near the coatings is bent towards itself to within a fourth of an inch, as shewn in fig. 38, the greater portion of the discharge, instead of passing through the long wire, the course of which is cut off by a dotted line in the figure, leaps across at the bend E; the proportion being greater the nearer the wire is at the bend, and the longer the course of the wire. Here the electricity finds a short course of the non-conducting air a better conductor than a long one of the conducting wire.

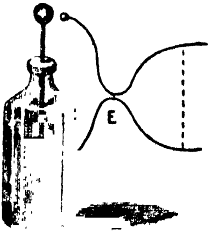


Fig. 38.

35. *Effects of Discharge.*—We have found that insulated bodies, when sufficiently influenced by electricity, like the pith-ball of the electric pendulum, are attracted and repelled at charge or discharge. If the particles of matter are more or less insulated conductors, we should expect to find something similar in them. This we actually do, for *mechanical action or heat,* the equivalent of mechanical action, *is always developed by discharge.* Non-conductors shew this most, as their particles offer the greatest resistance to discharge. When discharge takes place through air in the form of a spark, there is always a commotion of the aerial particles, and heat is developed; and when discharge takes place through glass, the material in the path of the discharge is broken into fragments or ground to powder. Even good conductors exhibit the same. When a large amount of electricity is made to pass instantaneously through a thin wire of metal, the wire is made red hot, and sometimes even vaporised. The small number of the discharging

particles have more work than they can accomplish in the time, and consequently act as if non-conducting.

36. *Electric Quantity and Tension* are terms based on the assumption that electricity is a fluid. Quantity is the amount of the fluid that a body contains as its charge, and the tension at any point on its surface (insulated electricity lies on the surface) is the depth—or if the depth remain the same, the density (Ger. *dichtigkeit*)—of the fluid at that point. The fluid may be so disposed on a body as to lie deeper, or denser, at one point than another, and it frequently happens that though the quantity of a charge be small, its tension, on a limited surface, may be very great. Without the fluid theory, we may arrive at a correct view of these terms. If I rub, say six inches of a glass tube, I produce a certain quantity of electric force; if I rub twelve inches of the same to the same amount, I double the quantity. If I rub the first six inches more energetically, I may give it twice the power it had before, and then the original quantity would be again doubled. In this last case the particles of air immediately touching the glass would be polarised twice as much as in the first two cases, the tension of the excited particles of glass is now doubled. The quantity has reference to the number of particles electrified, and the amount of force lodged in each; the tension has reference simply to the inductive force lodged in each. It is possible, as we shall afterwards find, to concentrate the force of many molecules on a few, the tension of the latter being as much greater than that of the former, as their number is less. Particles that are highly electrified must polarise powerfully the particles near them, and if powerful enough, cause discharge. Tension, therefore, is the power to polarise and effect discharge. (See also page 271.)

37. *Induction propagates itself in the direction where it has the least resistance to encounter.* If we supposed the row of polarised particles between A and PP (uninsulated), fig. 37, to be those of a conducting wire, discharge instantly takes place. The particles instantly give off their electricities to each other, and the two terminal particles discharge their outer halves, one on the ball, the other on the plate. The discharge takes place as if there were no other particles concerned

than the terminal ones, which are in opposite states. If the wire were insulated, discharge would take place only in the interior, leaving the two terminal halves ready for discharge when occasion offers. Insulated conductors thus only shew electricity on their outer surfaces, and in the line of action. But why, when the wire touches both, does discharge take place along it? The electric force of the ball can act on the air and on the wire. The particles of air offer considerable resistance to polarisation, those of the wire almost none. Electricity here, like all other forces, acts in the path of least resistance, the path most favourable to its action. If the facility of communication between molecules were more nearly equal in the air and in the wire, the inductive action would be directed in the proportion of that facility to each; but seeing that the facility offered by the latter is indefinitely superior to that of the former, the whole of the action is diverted from the air into the wire. This facility immediately leads to discharge and electric quiescence.

We have already seen that the shorter the passage the fewer are the particles to be acted upon, and the easier is it to act on them; that even a short non-conductor possesses to a certain extent conducting properties (fig. 38), whilst even a long conductor becomes non-conducting. The portion of the air between A and PP being a shorter passage to the ground than any other is consequently better conducting, and the action of the ball is more exerted through that channel than through any other. The tension of the electricity on A is greater towards PP than on any other side. If PP were circular, and extended nearly all round A, the whole of its surface could become equally active; and if A were charged in these circumstances, it would receive a much greater charge than when nothing but air was near it. This we find experimentally to be the case. The Leyden jar and condenser are illustrations of it. *The charge, therefore, that a body receives is always in proportion to the facilities it offers for induction.* If a body is so situated that it has nothing to act on, it receives no charge, or has no *electro-static capacity.*

28. *Discharge begins where the Tension is greatest.*—When A and PP are brought so near that a spark passes between them, it is likely that the discharge first begins at A, and extends to PP. The reason is this. The lines of polarised particles expand from A to PP, PP having the larger surface. The tension of the particles at the plate and at the ball is greater than in the middle, for the inductive action, acting on curve lines, can bring in there a larger number of molecules than at the ball or plate. The lines of polarised particles widen out in the middle. At the ball, the number of molecules is most restricted, and the tension there is highest. They then will first be forced to be conducting, or to form electrically a part of the ball, the charge is thus pushed forward towards the plate, and the inductive lines are contracted towards it. The charge is again pushed forward, and a further contraction takes place until it reaches the plate. If both bodies had the same size and shape, the tension being greatest at the ends and least in the middle, the spark would start simultaneously from each. The following experimental illustrations shew that when the tension is the same at both terminations, the spark or discharge first begins at the terminations. Wheatstone's experiment (50), afterwards detailed, shews that the discharge of a Leyden jar proceeds from both coatings at once, and ends in the middle. Electric discharge is so momentary in good conductors, that it is impossible, except by such contrivances as Wheatstone's, to determine the order of discharge. In solid non-conductors, where the discharge is necessarily much slower, we can trace it better. Matteucci placed together several leaves of mica between two metal plates in the manner of a Leyden jar, and kept the arrangement charged for some time. On taking the whole to pieces, he found the laminæ next the oppositely charged plates charged with the electricity of the plates, while those in the middle were without charge. The discharge, which had only partially taken place, began simultaneously at each end. Mica here acted as a slow conductor. The residual charge in a Leyden jar (49) arises from the electricities having penetrated so far into the glass.

We have hitherto taken no notice of the — E that, for instance, is said to be lost in the ground when glass is charged positively. Now it may be lost, and the — E induced by the glass on surrounding conductors may be new — E induced by it. But it is also possible, nay even probable, that this — E is none other than the — E said to be lost. If this be the case, the ground acts as much on the glass as the glass on the ground, and the action is precisely the same as in a galvanic circuit, where the polarisation proceeds in opposite ways, in two opposite directions, the action of the one strengthening the action of the other. However, it makes no practical difference, and it is simpler to suppose the insulated body to be the one centre of force.

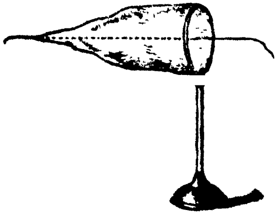
Distribution of Electricity.

39. *Effect of Extended Surface.*—We might take it almost as a self-evident truth, that the greater the surface over which electricity is diffused, the less is its power or tension at any particular point, and so we are taught by experiment. When two equal balls are insulated, and a charge is given to one of them, and then communicated to the other by contact with the first, it is found that both equally divide the charge, but that the tension of the electricity of each is one half of that of the originally charged ball. When a watch guard-chain is charged and laid on the plate of an electroscope by means of a glass rod, the gold leaves diverge most when the chain lies in a heap on the plate; and as it is lifted up, the leaves approach each other, shewing that as the exposed surface of the chain increases, the electric tension of each part diminishes. We are thus taught that a large surface feebly electrified is equivalent to a small surface highly charged with electricity. This can be accounted for by the theory of induction in the following way. It is assumed that electricity places itself where it can best propagate polarisation through the particles of the dielectric. In the case of the two balls, as each offered the same facility for induction, there was no distinction electrically between them, and an equal distribution necessarily took place. The polarising force, however unaltered in amount, having twice the number of dielectric molecules to act upon, can only effect half the amount of polarity in each.

The same method of explanation may be adopted in all such cases.

40. *Electricity found only on the outer surface.*—Experiment teaches us that electricity is exhibited only on the surfaces of conductors; this is shewn by the apparatus represented in fig. 39. A brass ball is suspended by a silk thread, and covered with two hemispherical surfaces of brass, which are held by insulating handles, and which exactly fit it. A charge is then communicated to the ball so compounded. When the hemispheres are withdrawn, they are found to take away all the electricity with them, not the slightest charge being left in the ball. The same fact is exhibited by a hollow ball placed on a glass pillar with a hole in the top large enough to admit a proof plane to the inside. When charged, not the faintest evidence of electricity is found on the inner surface, however thin the material of the ball may be. The edge of the hole should in this experiment be rounded at the edge, or covered with a ring of shell-lac, to prevent it discharging into the proof plane. The thinnest metal plate, when under induction, shews opposite electricities on its two faces. No electricity is found on the

Fig. 39.



inner surfaces of two gold leaves diverging under the same charge. Faraday attached a conical bag of cotton gauze to an insulated ring (fig. 40), and held it distended by a silk thread attached to the apex. On charging it he found, by the proof plane, the charge to be wholly on the outside, and no electricity whatever was found in the inside. By pulling the silk thread the other way, the bag was turned inside out. The electricity hereupon changed sides, and lay wholly again on the outside. We learn from these and numerous other experiments, that *electricity is only found on the outer surfaces of conductors in an envelope of inappreciable thickness.*

This fact is quite in keeping with the theory of induction, for the polarisation which a charged body exerts cannot be propagated towards its interior, which cannot possibly offer the corresponding opposite electricity, to complete the chain, and the outward polarisation can be manifestly best exerted on the very exterior, if we may use the phrase. That facility for induction determines the position of the charge, may be shewn by putting an uninsulated ball inside the cotton net (fig. 40), when the electricity will partially shift inside the net. See also the explanation given at the beginning of article 37 of the action of the molecules of a conductor under induction.

41. *Effect of Position and Shape.*—We are also taught by experiment that the distribution of electricity on the surface of insulated conductors is influenced materially by their form. An electrified ball, for example, exhibits the same tension on every part; and this we should expect, for there is no point *par excellence* where induction is facilitated. This, however, is not always the case, for when a conductor is brought near enough to the ball, the distribution is disturbed, being greatest towards the disturbing body, and least on the side away from it. If induction were propagated from the ball in the same way that light emanates from a candle, we should expect that the opposite electricity developed on adjoining surfaces ought to be of higher tension than on those more remote, in the same way that a body held near a candle is more strongly illuminated than more distant objects. The candle, however, does not shew itself brighter on the side next the near object

—the distribution of its brightness is the same as before. But in the electrified ball we have a crowding of electricity towards the shortest dielectric channel (37). It is to this concentration of electricity on the side of the approaching conductor that we owe the electric spark, and it is as we near the striking or sparking distance that this disturbance becomes decided. The concentration or fixing of electricity on the side of the thinnest and best dielectric is particularly illustrated in the condenser and Leyden jar, whose action depends upon it; but in these the dielectric must be very thin to secure decided effect.

When a conductor somewhat in the form of a prolate spheroid (fig. 41) is charged, and the electric tension of the several parts tested by the proof plane, it is found to be least at the thickest part, and to increase towards either end; and the difference is found to be all the greater as each end becomes more and more pointed. It is found likewise that the electric tension on a point is so great with a considerable charge as to destroy the dielectric condition of the air, the particles of which become electrified, and carry by convection, like so many pith-balls, the charge of the point to surrounding conductors. When a point is turned towards a charged surface, it acts as if the surface were almost in conducting connection with it; and when a point is in a charged surface, it acts as if the surface were joined to the ground or neighbouring conductors by semi-conducting wires. A flame also acts as a point. We therefore learn that *electricity concentrates on points and projections.*

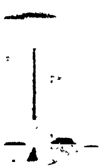


Fig. 41.

This is quite in accordance with the theory of induction. Let us take the case of a metal point presented to a positively charged surface. We may suppose its terminal molecules to be as shewn in figs. 42 and 43. If they were molecules of air, they would be polarised alike as shewn in fig. 42, and if we suppose them in this condition to be invested with conducting power, they would act precisely as the point in question, fig. 43. The shaded halves of the molecules are positive, the others negative. The light-shaded circles are neutral. The halves next the inducing body must be negative (fig. 42). The – E of the three molecules would neutralise the + E of the two in front of them, and the – E of the two again the + E of the one in which the point ends. In order that this should be, the two must furnish as much + E as the three of – E, and the one as much as the two. Consequently, from the action of the conducting particles on each other, the one must yield as much + E as the three, and be polarised three times as much. The effect of the whole three is thus lodged in the one (fig. 43); and if the point be prominent enough, the effect of the whole – surface connected with the point will be concentrated in the terminal molecule. The point here is supposed to be perfect, which we never have in practice, but ordinary points approximate more or less in their action to it. The point so strongly charged will react on the air, and cause all the lines of inductive force to concentrate on it. The facility with which the molecules of a conductor communicate their electricities one to another is no doubt the reason why the distribution of electricity on the surfaces of conductors appears to be that of a highly elastic fluid (31).

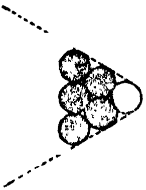


Fig. 43.

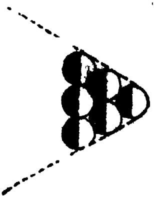


Fig. 42.

Electrometers and Electroscopes.

These words are generally taken as synonymous; electroscopes, however, should be applied to the instruments which give evidence of electrical excitement without giving the exact measure of it; and electrometers to such as shew both.

42. *Quadrant Electrometer.*—Fig. 44 represents the *quadrant electrometer.* It consists of a conducting-rod, generally of box-wood or brass, with a graduated semicircle attached

above, in the centre of which is a pivot for the rotation of a straw carrying a pith-ball at its outer end. It is used for electricity of high tension, such as that of the electric machine. When placed on the prime conductor of the machine, the whole becomes charged with + E, and the ball is repelled first by the electricity of the rod, and then by that of the prime conductor, the height to which it rises being seen on the semicircle. This is not an electrometer in the strict sense of the word, for although it tells us, by the straw rising and falling, when one tension is greater or less than another, it does not tell us by how much, the conditions of its repulsion being too complicated for simple mathematical expression. It can shew us, however, by the indicator standing at the same point, when the electric tension of the machine is the same at one time as at another.

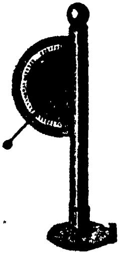


Fig. 44.

43. The *Gold-leaf Electroscope* is the most convenient instrument for testing electricity of feeble tension. One of the best of its forms is shewn in fig. 45. A glass ball, about four inches in diameter, rests on a brass tripod, and its neck, about an inch in diameter, is enclosed by a brass collar fixed with shell-lac. A brass plate, with a hole of one-fourth of an inch in diameter in the middle of it, can be screwed air-tight into the collar. Before it is so fitted, a brass rod, one-eighth of an inch in diameter, is fixed by shell-lac or sealing-wax into the hole in the middle, so as to be perfectly insulated from it. The upper end of the rod ends in a brass ball, and the lower end is filed on each side, to allow of two strips of gold-leaf, an inch in length, being attached to it. Before the plate and leaves are finally fixed, the interior of the ball is thoroughly dried, by passing hot dry air into it, so that the ball contains no moisture to carry away the charge of the leaves. When the plate is screwed to the collar, there is no

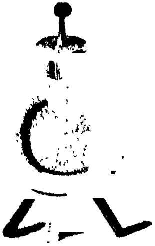


Fig. 45.

communication between the included and external air. The insulation of the leaves is complete, and they keep their charge, in dry weather, for hours together. When the instrument is used, it may be charged directly, by contact being established with the ball and the body whose electricity we would examine, or a charge may be carried to it by the proof plane, when the leaves diverge according to the charge communicated. When we would ascertain simply the kind of electricity with which a body is charged, we proceed in the following way. A glass tube is rubbed, and brought into the neighbourhood of the brass knob; the leaves diverge by induction, and, when so diverging, the knob is touched with the finger, and the leaves fall to their original position, for they are then out of the line of action. In this state, − E is fixed by the action of the + E of the tube on the side of the knob next it, and the corresponding + E is lost in the ground. When the finger is removed, the + E is cut off, while the − E remains in the knob; and its presence is manifested by the leaves diverging permanently after the removal of the tube. If, now, a positively electrified body be brought near the knob, it draws away the − E from the leaves, and they consequently fall in; but if a negatively electrified body be brought near, it sends the − E more to the leaves, so that they diverge further. We are thus enabled to distinguish between a + and a − charge. But it may be asked, why not charge the electrometer immediately with the glass? There are two difficulties in the way of this. If the glass is powerfully electrified, it gives too great a charge; and if feebly, contact between the knob and the glass cannot be effected, although its electricity acts powerfully by induction. We therefore bring the glass rod near the electrometer, and when the leaves diverge sufficiently, we touch the knob with the finger, and withdraw first the finger, then the rod, and the leaves diverge as before. For the more delicate use of the gold-leaf electroscope, see CONDENSER.

44. *Coulomb's Torsion Balance* (fig. 46) has played an important part in examining the laws of electric forces. A glass canister, A, is placed on a wooden frame, and is covered above by a plate of glass or wood; in the middle of this

plate a round hole is cut, over which is fixed, by wooden fittings, a long glass tube, B, having the graduated rim of a circle attached at its upper end. A circular plate, resting on this rim, closes the upper end of the tube; and when it is turned round, a mark upon it tells the number of degrees through which it has been moved. A cocoon thread or very fine wire is tied to a hook in the centre of the lower side of this plate, and thence descends to the body of the canister. It carries below a collar of paper, or other light material, in which a needle of shell-lac is adjusted, having a disc of gilt paper placed vertically, or a gilt pith-ball at its one end and a counterpoise at its other. When the plate above is moved through any number of degrees, the needle below, impelled by the torsion of the thread, comes to rest at the same number on the scale below. This last consists of a strip of paper divided into degrees, pasted round the cylinder at the same height as the needle. In the cover of the canister there is another opening, for the admission of a ball insulated at the end of a rod of shell-lac, and which, when supported by the cover, is on a level with the paper disc of the needle. When the instrument is adjusted for observation, the mark on the upper plate and the paper disc stand each at the zero-points of their respective scales, there being of course no torsion in the thread. The ball is removed, to receive a charge from the body under investigation, and is then placed in the cylinder, when the disc is first attracted, then repelled. Suppose that the disc be driven 40°, as shewn by the lower scale, from the ball, and that the upper plate has to be moved in the opposite direction, through 160° of the upper scale, to bring it back to 10°, the total degree of torsion is 160° + 40° = 200°. If the ball and disc be now discharged, and another charge be given to the ball, which requires 250° of torsion to place the disc at

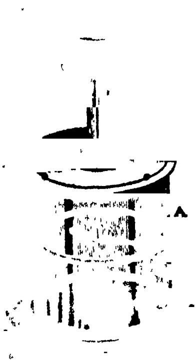


Fig. 46.

10°, we have the relation 200 to 250 as that of the repulsive forces of the two charges, for the amount of torsion in degrees is proportional to the twisting force. Without entering further into detail, we may state the two laws that Coulomb established by this instrument: *The intensities of the mutual repulsion or attraction of two invariable quantities of electricity of the same or different names, are in the inverse ratio of the squares of the distance at which these act. The intensities of the total repulsive or attractive action of two electrified bodies placed at an invariable distance, are proportional to the products of their electric charges.* The latter law shews that, when two different tensions are tested by the proof plane and torsion-balance, they are to each other as the square root of the observed forces of repulsion.

Electric Machines.

In the tube of glass and silk rubber we have the embryo of the electric machine, viz., a body which, when rubbed, is positively electrified, and its rubber negatively. The first requisite we should expect in a *machine* of this nature is a large surface, to give a great amount of electricity. But there is another already casually referred to: glass being a non-conductor, the electricity formed on its surface has not a combined action, so that some arrangement is necessary to collect it, and render it available—to act, in fact, as its conducting reservoir. This portion of the machine is denominated the *prime conductor.* The rubbed surface of the electric machines is either a cylinder or plate of glass, hence we distinguish them into cylinder machines and plate machines. The former, from their more compact form, are the more manageable; and the latter, from both sides of the glass plate being rubbed, are the more powerful forms of the instrument.

45. *Plate Machine.*—The description of Winter's plate machine (fig. 47) will be quite sufficient to shew the general requirements and construction of electric machines. It was designed by Carl Winter of Vienna, and its merits, as well as

those of some of the best forms of electrical apparatus, have been made widely known by two well-known German works, Müller's *Physik* and Frick's *Physikalische Technik*. The first machine on this principle in this country was made under the author's superintendence in 1858. It is one of the best existing forms of the machine. The glass plate is turned on the axis *ab*, by means of the handle *c*. The longer end of this axis, consisting of a glass rod, moves in the wooden pillar *d*, and the other rests in the wooden head of the glass pillar *e*. The plate is thus completely insulated, and little loss of its electricity can take place through its supports. The two rubbers, one of which is shewn on the outside, in fig. 48, are triangular pieces of wood, covered with a padding of one or two layers of flannel, enclosed in leather, and they present a flat hard

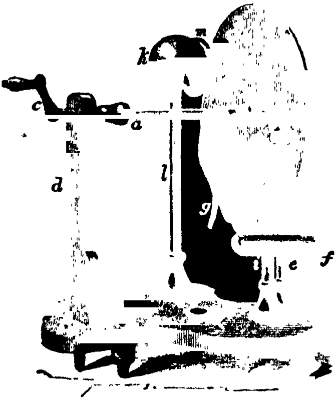


Fig. 47.

Fig. 48.

surface to the glass, so that friction between it and them takes place in every part. They are placed in a wooden frame on each side of the plate, and the pressure is regulated by metal springs, fixed to the outside, between them and the frame. Before use, they are covered with an amalgam of mercury, zinc, and tin, which is made to adhere with the aid of a little grease, and which increases immensely the production of electricity. The surfaces of the rubbers are therefore conducting, and are made to communicate by strips of tinfoil with the *negative conductor*, *f* (fig. 47). To prevent the electricity of the glass from discharging itself into the air, before reaching the prime conductor, each rubber has a non-conducting wing fastened to it, which is made of several sheets of oiled silk, kept together by shell-lac varnish, beginning at the rubber with several, and ending with one or two sheets. When the machine is in action, electrical attraction makes them adhere to the plate; but when it is out of action, they may be kept up by a split pin, *g*. As the plate turns, the rubbers are kept in the frame by their ledges, *h*. The whole framework of the rubbers and negative conductor is supported by the short glass pillar *i*, so that it can be insulated when required. The prime conductor, *k*, is a brass ball insulated on the long glass pillar *l*, and to prevent the edges of the ball at the junction dissipating the electricity, the pillar enters the ball by a trumpet-shaped opening. The collection of the electricity from the glass is made by a row of points placed in the grooves, inside of two wooden rings, *m*, *m*, which are attached on each side of the plate to a piece of brass projecting horizontally from the ball of the conductor. The grooves are covered with tinfoil, which conveys the collected electricity to the ball, and the points are kept out of the way of injury by not projecting beyond the grooves.

A section of the ball of the prime conductor is shewn in fig. 49. There are four openings into it: the lower one for the head of the supporting pillar; the one at the right for the attachment of the collecting apparatus; the one at the left for the stalk of a small brass ball; and the upper one for admitting the lower end of a large wooden ring, removable at pleasure. This last forms the peculiar feature of Winter's machine. It consists of an iron wire bent into the shape shewn in the figure, carefully covered all round with polished wood, and communicating by a brass pin at the foot of the stalk on which it stands with the prime conductor. To receive the sparks from the machine, an appendage (fig. 50) termed the spark-drawer is provided. This consists of a wooden pillar of the same height as the prime conductor, in the head of which a brass rod slides, with a large flat ball at the one end and a small ball at the other. All the fittings of the machine are of wood, no metal being used but for the prime and negative conductors. The loss caused by metal fittings in ordinary machines is very considerable. The insulating pillars should be, if possible, of green glass, which, from the absence of lead, is less conducting than flint glass. It is desirable, likewise, to cover them with shell-lac varnish, which prevents the formation of a conducting layer of moisture on them from the atmosphere. On using the machine, it is first necessary to connect the negative conductor by a wire or chain with the ground. As the plate is turned, − E is developed on the rubbers, and led to the negative conductor; and + E is formed on the glass, which is collected by the points, and transferred to the prime conductor. If the

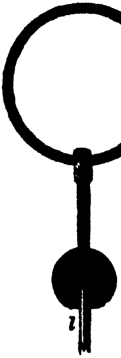


Fig. 49.

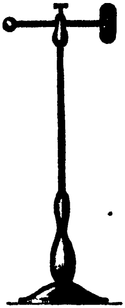


Fig. 50.

negative conductor were insulated, the electricities of both conductors, being of opposite names, and equal in amount, would act inductively on each other, so that the + E of the prime conductor would be to a considerable extent bound by the − E of the other conductor. When the latter is connected with the ground, its electric tension is no higher than is due to the inductive action caused by the prime conductor, which at the distance is not great, so that the electricity of the prime conductor is free to throw itself on the objects presented to it. To lessen this attraction, and at the same time to insure the insulation of the + E, both conductors are placed as far apart as possible, the distance in Winter's machine being nearly the diameter of the plate. If − E is wanted, the negative conductor is insulated, and the prime conductor connected with the ground, when sparks of − E are given off by the negative conductor.

46. *Disruptive Discharge in Air. Spark, brush, glow* (Fr. *étincelle, aigrette, lueur;* Ger. *Funke, Büschel, Glimmen*).—The term disruptive discharge is applied to all cases where discharge is attended with a disruption of the particles of the dielectric. The various forms of disruptive discharge through air can be well seen with Winter's machine. The negative conductor being connected with the ground, with a two-foot plate, we may observe them in the following order. On turning the plate once or twice, a faint snapping sound is heard, and, when the room is darkened, a flickering spark is seen to be thrown out from the two-inch ball projecting from the prime conductor, which has the form of a bush, without leaves, with trunk, branches, and twigs, about ten inches in height. This is one form of what is called the *brush discharge.* Its general direction is horizontal, or not much inclined from it, but it turns to the hand or other flat conductor brought near it. If it be received on a ball, its various branches concentrate on it. If the brush proceed from the end of a brass rod, instead of from a ball, it becomes very much diminished in size, and resembles a brush of feathers. The brush discharge, though apparently continuous, has been found by Wheatstone to consist of a series of successive brushes.

When discharge is effected from a point, a star or *glow* of light marks its termination, while strong currents of air proceed from it, which are strong enough to blow away the flame of a candle. These currents accompany more or less the various forms of the brush discharge. The particles of air thus carry away the charge from a point to surrounding conductors, and hence a point is said to discharge itself by convection. The glow is more readily got, and becomes much more extended in rarefied air. A tall receiver, with a ball above connected with the machine, and a ball below connected with the ground, when exhausted, presents the appearance of a pillar of flickering mauve-coloured flame. When a vacuum tube (that is, a tube exhausted of air, with platinum wires hermetically fixed in its ends) is held near the machine, flashes of light pass through it, and continue to pass at intervals even after the machine has ceased to act. The flickering light thus produced bears a striking resemblance to the aurora borealis. No sound accompanies the glow. If we connect the brass rod of the spark-drawer with the ground, or the negative conductor, and bring the flat ball opposite to the small ball on the prime conductor, straight brilliant *sparks*, each sounding like the crack of a whip, pass between them so long as the distance does not much exceed two inches. Beyond that distance, the sparks become somewhat crooked, and at about four inches, the discharge begins to take the form of a brush. If, now, the ring be placed in the conductor, the sparks again pass with readiness, and the brush does not again take place till the ball of the spark-drawer is eleven or twelve inches off. The long sparks thus obtained with the aid of the ring are decidedly crooked or forked, with strongly-marked lateral branches, which become all the more marked as they lengthen. It would thus seem that the spark has a tendency to break up into branches. When the striking distance is small, this is not so perceptible; it is then straight and its branches scarcely observable. As the distance increases, it is crooked with well-marked offshoots; and when the distance is too great, it splits up entirely into a bush or brush.

The function of the ring of Winter's machine is therefore to increase enormously the length of the spark. This would seem to arise in the following way: Quantity as well as high tension of electricity is requisite for the long spark. Without the ring, the electricity collected on the prime conductor concentrates on the projecting ball, but it cannot gather strength enough to make a full discharge into the neighbouring spark-drawer, for before the quantity is sufficient, the tension of the electricity on the small ball has pushed the polarisation of the molecules of air to their utmost, and a partial or overflow discharge in the form of a brush ensues. When the ring is added, from its thinness and prominent position, it diverts the electricity into it; and before the tension of the electricity on the small ball again rises to discharging point, a large charge is accumulated in the compound conductor, which finds full vent in a powerful and concentrated spark. The wooden envelope appears to act to the core as the oiled silk to the plate; it prevents discharge into the air. The influence of the large flat ball of the spark-drawer is of importance; it concentrates, from its size, the inductive action of the charge on itself, and from its flatness, it cannot hasten a premature discharge. Long sparks do not necessarily imply a very powerful machine, but they guarantee good production of electricity, and an insulation so perfect that no power is squandered. For the generality of electric experiments, sparks of one or two inches are amply sufficient. These, Winter's machine gives readily without the ring; and when occasionally long sparks are wanted, the extension of the prime conductor can be added without inconvenience. It might be supposed that while the long sparks pass, the machine works more powerfully than at other times; but such is not the case, for the long spark occurs only occasionally, and the short one almost incessantly. All the forms of disruptive discharge are accompanied with the peculiar *electric odour* which arises from the production of ozone, a peculiar modification of oxygen.

47. *Cylinder Machines.*—Fig. 51 represents a cylinder machine. A is the glass cylinder, E the negative conductor, insulated on a glass pillar, D, which can be adjusted by the screw, *s*, in the sole of the instrument. The rubber is

attached to the negative conductor, and the flap of oiled silk, KK, to the rubber; G is the prime conductor, insulated on the glass pillar H; B, B are the wooden standards in which the axis of the cylinder works. The rest of the machine is sufficiently explained by the figure.

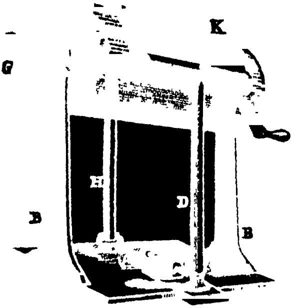


Fig. 51.

48. *Experiments with the Electric Machine.—To illustrate Attraction and Repulsion.*—A wooden head with hair on it is fixed to a metal rod, and placed on the machine. As soon as the machine begins to work, the hairs stand on end apart from each other. When the hand is placed above the hairs thus excited, they converge and cling to it. The hairs being + and the hand −, attraction takes place between them. Between two bodies, one electrified and the other connected with the ground, there must always be attraction. The *electric dance* (fig. 52) is another illustration. The plate E is hung from CD, connected with the machine; CD stands on an insulating pillar AB. Below E lies the uninsulated plate F. Pith figures are placed on the uninsulated plate. When the machine is turned, the two plates are oppositely electrified, and the pith figures are alternately attracted and repelled by each. They keep thus dancing between the two so long as the machine acts, or until they leap away under the excitement. The same thing is shewn when the upper and lower plates form

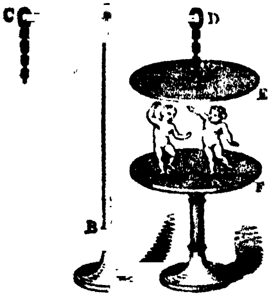


Fig. 52.

the end of a glass cylinder four or five inches in height, and pith-balls placed inside instead of figures. The balls are kept in continuous upward and downward motion between the plates, and, like the figures, discharge convectively the upper plate. A great many electric toys are constructed on this principle. Among them may be mentioned the *electric chimes*, where bells hung by silk threads, are kept striking alternately bells connected with the machine, and others connected with the ground.

The effect of Points and Flames.—When the machine is in action, and sparks of several inches in length are passing, they instantly cease when a sharp metal point held in the hand is presented to the machine within a few feet of it. If a pointed rod be placed on the machine, no spark can be got from the prime conductor; powerful currents of air proceed from the point sufficiently powerful to turn a small wheel furnished with paper vanes, or to blow away the flame of a candle. Persons standing near the machine, feel as if cobwebs were on the face, arising from the charge being disseminated by the point. The reaction of the air on points can be made to move the points themselves. This is generally shewn by taking a wire pointed at both ends, and bending it so that its points are at right angles to it and on opposite sides of it, and poising the whole on a point on the machine. When the machine is in action, the points are driven backwards, and the wire revolves on the principle of a reaction wheel. In the dark, the points describe a luminous ring from the glow at them.

When the flame of a candle is held near the machine it acts like a point; if uninsulated, it acts more decidedly than when insulated. In the latter case, it appears to point towards the machine and out from it, acting like a double point—one discharging the machine, the other discharging the flame into the air.

The *heat of the spark* is shewn by holding a spoonful of ether below the small projecting ball so as to receive a spark from it. The spark instantly kindles the ether.

Communication of Electricity.—Conductive.—A person standing on an *insulating* stool (that is, a stool with glass legs), with one hand on the machine, can with the other send sparks to everything and everybody about him. In this position he can light with his finger a jet of gas or kindle ether. *Inductive.*—The most extraordinary experiment that can be performed with Winter's machine, is the lighting of a gas-jet by a person wholly unconnected with the machine, and standing some eight or ten feet from it. If the person so situated holds the blade of a knife or other point over the gas-burner, at a distance only short of touching, at each long spark from the machine, a small spark passes between the blade and the burner, and this ignites the gas. The reason is as follows: The body of the person in question is electrified negatively by the extensive prime conductor of the machine acting inductively. When the spark passes, the ring is discharged, and its inductive power for the moment ceases, and the negative electricity of his body, now no longer attracted by it, returns to the ground, and taking the easiest route causes the spark in question. This is quite similar to what is known in thunderstorms as the *back-stroke* (Fr. *choc en retour;* Ger. *Rückschlag*). A person in a prominent position, under a highly-charged cloud, experiences a violent, sometimes fatal shock at the same time as a flash of lightning, although the flash was not at all near him.

The *physiological effect* of the spark may be felt by any one holding the back of his hand near the machine so as to get a spark from it. A ten-inch spark from Winter's machine produces a stinging sensation accompanied by a nervous twitching, and this may be felt by a dozen persons at once, joined hand in hand, the first presenting his free hand to the machine, and the last having his free hand connected with the ground or negative conductor. The last, however, receives a less shock than the first, because since each person is badly insulated on leather soles, more or less moist, so much electricity descends to the ground as it passes through each.

Bound Electricity.

49. *Leyden Jar* (Fr. *Bouteille de Leyde;* Ger. *Leydner Flasche*).—This is a glass jar (fig. 53), with a coating of tinfoil pasted carefully inside and out, extending to within a few inches of the mouth. This last is generally closed by a wooden stopper, through which passes the stalk of a brass knob or ball, surmounting the whole. The connection between the inside coating and the ball is completed by a chain extending from the stalk to the bottom of the jar. If this jar be put on an insulating stool, so that sparks can pass from the prime conductor of a machine to the knob, when the jar is thus insulated, one or two sparks pass, and then the charge seems complete, for no more sparks will follow, though the action of the machine is continued; or if they do, they are immediately dissipated from the knob in a brush discharge. If then, however, the knuckle of the experimenter be brought near the outer coating, sparks begin again to pass freely; and for every spark that passes between the machine and the knob, a similar spark passes between the knuckle and outer coating. This continues for some time, and then the jar appears to be again saturated. It is now said to be fully charged. The outside of the jar can, in this state, be handled freely, and if it be still on the insulating stool, so may also the knob, although, when the hand first approaches, it receives a slight spark. But if, when the experimenter has one hand on the outer coating, he bring the other hand to the knob, before it can reach it, a straight, highly brilliant spark passes between the knob and his hand, and he experiences a shock of great violence. If he try the same thing again, a feeble spark and shock again ensue, and the jar is now thoroughly discharged. As it is highly inconvenient, if not dangerous, to discharge the jar through the body, *discharging tongs* (fig.

Fig. 53.

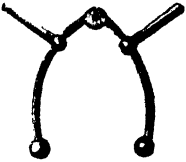


Fig 54.

54) are used for that purpose, which consist of two brass arms ending in balls, and moved on a hinge by glass handles.

The following account may be given of the action of the jar: When a spark passes between the conductor and the knob, the + E thereby communicated to the inner coating induces polarity in surrounding conductors, the – E being turned towards it. From the knob, it can act upon a wide but distant range of conductors, through the air as the dielectric; and through the glass as dielectric, it can act upon the outer coating. Now, as the outer coating is very much nearer than other conductors, and as glass is a better dielectric than air, by far the most important direction of induction, when the jar is uninsulated, is through the glass. We have, therefore, the electricity given to the knob and inner coating divided, as it were, into two inducing charges—one to the further conductors, and the other to the outer coating. The former of these we may call the free charge, as it acts in the usual way through the air; and the latter, the bound charge, for it has a special conductor and dielectric. Electricity, which, from peculiar inductive facilities, acts only in one direction, is called *fixed, bound,* or *disguised electricity* (Fr. *électricité dissimulée,* Ger. *gebundene Electricatät*). When the jar is insulated, we find that after one or two sparks it refuses to take more. This comes from the outer coating refusing to be further polarised, or, which is the same thing, the insulated electricity can more easily transmit polarisation to surrounding conductors through the knob than by means of the + E induced on the outer side of the outer coating. When, however, the outer coating is connected with the ground, either by spark or contact, the polarisation can reach its final termination, the ground, much more easily through the thin sheet of glass than through the air, so that every spark that the jar now receives goes, for the most part, to the bound charge, and a small fraction only to the free charge. What goes to the bound charge must have a corresponding – E on the outside coating; and for every amount of – E thus fixed on the outer coating, a corresponding amount of + E must be sent from the outer coating, either silently, when in contact, or by spark, when nearly so, into the ground; and what goes to the free charge has its – E imperceptibly induced in surrounding conductors. The jar thus receives rather more + E inside than – E outside; the latter, however, being by far the largest portion of the total – E induced. After a few more turns of the plate, a second limit is reached, and the sparks refuse again either to travel or to be retained. This arises from the air offering an easier channel for induction than the glass, the particles of which now offer more resistance to further polarisation than those of air to a disruptive discharge. The thinner the jar is, the longer must it be before this state of things ensues, for the greater then is the facility for induction offered by the glass, and the less therefore will surrounding conductors acting through the air come into competition with the outer coating. The charge which the inner coating can receive is in proportion to the facility it has for induction. The thinner the glass, therefore, the greater will be its charge, and the less the proportion of the free to the bound charge. If the glass could be made of indefinite thinness, so as to offer perfect facility for induction, other conductors would not then come into competition with the outer coating. The free charge could not then exist, and there would be no limit to the charge which the jar could receive. Practically, however, there is a limit to the thinness of the jar, because when the particles of the glass become too highly polarised, they discharge into each other disruptively, for as the glass gets thinner the polarisation of its particles rises higher; and when it is too thin, the polarisation rises higher than the cohesion of its particles can bear, and a disruptive discharge takes place through it. Such a *spontaneous discharge* sometimes occurs with ordinary jars at their thinnest part; and as the fracture which it there causes in its passage makes the jar useless, it is usual not to charge a jar to saturation. The beau ideal of a Leyden jar would be one whose dielectric was perfectly insulating, and yet offered no resistance to the propagation of polarity among its particles, a condition manifestly unattainable. According to Wheatstone, *the amount of electricity which a jar can receive*, provided it be of uniform thickness, *is proportional to the coated surface, and inversely proportional to the square of the thickness of the glass.*

The two charges are bound by mutual attraction to each side of the glass; but if both coatings could be simultaneously removed, as in the condenser, each would give striking evidence of its high electric tension. The outside coating can be touched without shock, for the − E is next the glass, and the + E has been lost in the ground, of which the outer surface of the coating, as well as the hand, forms a part. The inner coating, or its representative knob, may not be touched while the jar is uninsulated, for the discharge of the two coatings would be effected through the ground and body. When it is insulated, it may be touched, after, however, receiving a small spark, arising partly from the discharge of the free charge. The outer coating becomes here the insulated or charging coating, which must always have more electricity than it binds on the other coating; for although the other coating offers the greatest facility for induction, surrounding conductors still offer some facility, and divert some of the charging electricity as a free charge on them. Consequently the spark got from the knob is partially made up of the free + E already there, and partially from the + E set free by a corresponding amount of − E being set free in the outer, now the charging coating. When now we touch the outer coating, a − spark is got from it, and when we again touch the knob, a + spark; and thus, while the jar is insulated by touching alternately the knob and the outer coating, we gradually discharge it. A toy, called the electric spider, prettily illustrates this action. A ball connected with the outer coating is placed at the distance of one or two inches from the knob of the jar which is insulated, and a piece of pith made up so as to resemble a spider is hung by a silk thread between. The spider keeps moving between the two balls, under the influence of the electricities alternately liberated from each coating.

When we wish to discharge the jar with the tongs, we place one ball on the outer coating, and bring the other round to the knob, when the discharging spark takes place. The length of this spark is many times longer than the thickness of the glass, which shews that a discharge takes place more easily through the air than through a glass plate of much inferior thickness. On bringing the ball of the tongs, after the first discharge, nearer to the knob, a feeble *secondary* follows, arising from the electricity which, under the intense action, had penetrated the glass, in the endeavour to force a conducting passage through it, being partially left in it. It is to this state of conduction into which the surfaces of the glass are forced, that we may attribute the fact, that the charge appears to lodge more on the glass than on the coatings, the latter merely serving to aid in giving completion to their semi-conducting state. This is usually illustrated by a jar with movable coatings, which, when charged, can be taken to pieces. The jar being insulated, the inner coating is first removed, then the jar is lifted from the outer coating. Both coatings being completely discharged, the whole is again put up, and a discharge of very considerable power is obtained.

A series of insulated jars can be charged simultaneously with the same charge. They are arranged so that the knob of the first jar is connected with the machine, and its outer coating with the knob of the second. The outer coating of the second is in the same manner connected with the knob of the third, and so on, the last outer coating being connected with the ground. The whole is discharged by bringing the knob of the first in connection with the outer coating of the last. This is called the *charge by cascade* The outer coating of one jar, and the inner coating of the next, is placed in the same circumstances as each of the cylinders (fig. 35), only they are separated by glass instead of air from the next in the series, and from the extent of surface and proximity of each, they are polarised much more powerfully.

For great power, large surfaces are necessary. This can be obtained either by constructing a large jar or by uniting several small jars together, so as to act as one. The latter method is preferable, as we can vary the surface according to the number of jars employed. A combination of small jars united together as one is called an *electric battery*. A very convenient form of electric battery is shewn in fig. 55. The knobs of each jar communicate with a large central one by means of arms of brass moving on hinges, and the outer coatings are put in conducting connection, by being placed on an insulated stool covered with tinfoil. The interior coatings are conveniently charged by a long projecting arm from the central knob, and the exterior ones by connecting the stool with the knob of the unit jar, or by a wire with the ground. Any jar can be thrown out of action by throwing back its arm.

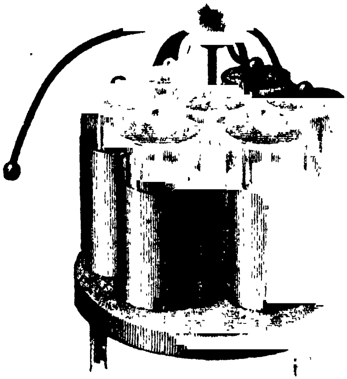


Fig. 55.

With respect to the *striking distance*, or that through which the air-discharge takes place, it has been found that it *is proportional to the amount of the charge, and inversely proportional to the extent of the coatings.* Thus, when a jar is half charged, the striking distance is half what it is with a full charge; and to keep the same striking distance for a jar of twice the size, a double charge is necessary. The amount of the charge is correctly enough known by the number of turns of the plate of the machine. When great accuracy is wanted, the outer coating of the insulated jar or battery is made to spark into the knob of a small jar, whose outer coating is connected with the ground. A ball connected with the outer coating of the small jar is fixed so near the knob, that when charged the jar discharges itself. Each discharge of the small jar measures so much electricity fixed on the large jar; such a measurer is denominated a *unit jar.* The action of the unit jar shews us that a small surface frequently discharged, is equivalent to a large surface once discharged.

Experiments with the Leyden Jar or Battery.—By discharging the Leyden jar or electric battery through particular channels, we obtain some beautiful illustrations of the power of electricity. When the discharge is effected through thin wires of gold or platinum, the heat accompanying its passage is so great as to dissipate them in vapour. The expansion of the air caused by the spark is shewn by the *electric mortar.* This is a wooden mortar with two wires entering air-tight at the opposite sides of the breach, with a small wooden ball fitting closely in the muzzle. The spark passing between these wires in discharge causes a sufficient expansion of the air within the mortar to drive the ball to some distance off. When the discharge is made through gunpowder, it tosses the grains violently about, but causes no ignition; when, however, it is retarded by introducing an imperfect conductor, such as a wet string, into the circuit, the gunpowder is fired. When the discharge is made through glass by two points pressing against its opposite surfaces, a small hole is drilled into the glass. To assist in such experiments, the universal discharger (fig. 56) is used. This consists of two arms of brass mounted on glass pillars, so that their position and distance can be easily adjusted, and of a small movable table placed between them, the whole resting on a wooden foot. When the discharge of a Leyden jar is made through a number of individuals, each receives an equally powerful shock. The want of insulation here does not cause a loss as when they receive a spark from the machine, for the

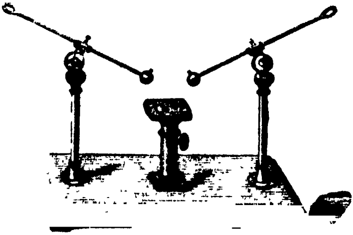


Fig. 56.

electricities of the two coatings have each other, not the ground, for their final termination.

50. *Velocity of Electric Discharge.*—The rapidity with which electric discharge takes place is so great, that we might well despair of reaching any definite information about it. Wheatstone, by means of a revolving mirror, determined its rate of propagation in certain circumstances. A small mirror was made to revolve fifty times a second, and the reflection of the electric spark was observed in it. Any one who takes a mirror in his hand and makes it revolve, sees that objects are apparently displaced by it, and it admits of an easy geometrical demonstration, that the reflected image describes an angle the double of that of the mirror. If, while the small mirror rotates at this rate, the image of a spark should shew a displacement of 90°, we know that the mirror has moved through 45°, and the time during which this takes place is $\frac{45}{360}$ of $\frac{1}{50} = \frac{1}{400}$ of a second. If the duration of the spark, then, had been $\frac{1}{400}$ of a second, we should have seen its image move through 90°. The eye, however, during this time would not have been able to discern any difference between the beginning and the end of the spark, so that the 90° would have appeared as one arc of light. Examined in this way, however, the spark of a machine and of a Leyden jar were seen as if the mirror had been at rest. Thus analysed with an apparatus where a duration of $\frac{1}{36000}$ part of a second would have shewn an arc of 1°, the electric spark appears instantaneous. The discharge of a Leyden jar through a long wire is not so instantaneous. Wheatstone's method of finding this was as follows: Six balls (fig. 57) were arranged in pairs, each pair being quite near the other. The ball 2 was connected with 3 by a copper wire a quarter of a mile in length, so were also 4 and 5—the dotted lines in the figure marking simply the connection. When discharge took place, the electricity of the inner coating was communicated to 1, and of the outer coating to 6. Supposing charge to travel from the

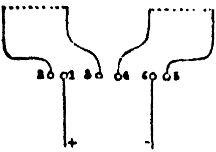


Fig. 57.

inner to the outer coating, it would proceed from 1 to 2 by spark, then by the long copper wire to 3, by spark to 4, by the other long wire to 5, and by spark to 6. To the eye, the three sparks seemed simultaneous. In the mirror, however, they presented the appearance of three arcs of equal length, the middle one rather behind the others (fig. 58). In this instance, the mirror revolved 800 times a second, and the retardation of the middle line was about ½°. The time, therefore, taken by the discharge to travel from 2 to 3, or 5 to 4, a quarter of a mile, was $\frac{\frac{1}{4}}{360} \times \frac{1}{800} = \frac{1}{1,152,000}$ of a second, which corresponds to 288,000 miles per second; greater than the velocity of light, which is only 194,000 miles per second. In the same manner, it was calculated from the lengths of the arcs, which were 24°, that the duration of each spark was $\frac{1}{24000}$ of a second. It thus appeared that the discharge was a successive one, not, at least, as instantaneous as through a short conductor. This prodigious velocity is only that of discharge, not that of electric action. The fact of both side-sparks occurring at the same instant, shews that induction must have been fully established along the whole line before discharge took place. One would imagine, from the dual nature of electric force, that the velocity of induction must be indefinitely great.

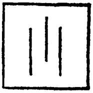


Fig. 58.

51. *Condenser*, the apparatus used in conjunction with an electrometer to increase its sensibility, and render it available for indicating the presence of very feeble electricity. A condenser of the simplest form is shewn in the accompanying fig. 59. A is a gold-leaf electrometer. The condensing apparatus consists of the two brass plates B and C, which are placed horizontally, the lower one being connected with the metal rod to which the gold leaves are attached, and the upper one being provided with an insulating glass

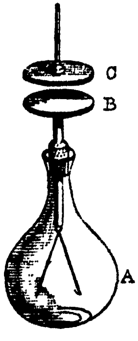


Fig. 59.

handle. These plates are accurately ground, the one to the other, so that when placed upon each other they touch in every part. Their inner surfaces are covered with a very thin and equable layer of shell-lac. When an observation is made, the excited body is brought into contact with the lower plate, and the finger of the observer is laid upon the upper. This being done for a sufficient time, the finger is first removed, and then the excited body, after which the plate, C, is lifted by its handle parallel to the other plate, the gold leaves at the same time diverging under the influence of the electricity left in the lower plate. The same observation might have been made with the positions of the finger and the excited body reversed, but the leaves would then be charged with the opposite electricity to that of the excited body. Reverting to the first case, the electricity to be tested is communicated to the lower plate in small successive charges, which, acting through the thin layer of shell-lac, induce, as in the Leyden jar, a corresponding charge of the opposite electricity on the lower surface of the upper plate, and send the similar electricity of the upper plate through the finger into the ground. Each weak charge of electricity given to the lower plate is not allowed to dissipate, but is kept fixed or bound by the corresponding charge of the opposite electricity which it has induced on the upper plate, so that an accumulation of such charges takes place. As yet, however, there is no excitement visible in the gold leaves, the electricity so condensed in the plate B being capable of acting only in one direction—viz., towards the charge of the upper plate. When, however, the plate C is removed, the collected electricity of the lower plate being no longer restrained to act towards it, immediately extends to the leaves below, and causes a marked divergence. In this manner, electricity of too low a tension to affect immediately the gold leaves can be condensed, so as to possess the power of doing so.

It is found that the efficiency of the condenser depends upon the accurate grinding of the plates, the thinness and evenness of the layer of shell-lac with which their inner surfaces are varnished, the size of the plates, and their parallelism on removal. This last is of the utmost importance; and it is found, where numerical results are wanted, that little dependence can be placed on the parallelism attained by the hand. For more accurate observations, the condenser is made quite separate from the electrometer. The plates are in this case attached vertically to two wooden pillars, on which they are insulated, and which slide in a horizontal groove made in the sole of the instrument. The plates, thus guided by the grooves, are made to approach and to retire from each other with their faces parallel. In a condenser of this description, no shell-lac varnish is used, the air between the plates acting as the dielectric in its place. When one of the plates is connected with the knob of the electrometer, the observation proceeds as already detailed.

52. *Electrophorus.*—This generally consists of a tin mould filled with shell-lac, and a movable metal cover, with a glass handle, as shewn in fig. 60. The shell-lac is poured in when melted, and it is mixed with some other substance, to make it less brittle. Five parts of shell-lac, one of wax, and one of Venice turpentine, is given as a good mixture. When used, the surface of the cake of shell-lac is smartly beaten with a cat's fur or foxtail. The cover is then put on, and touched with the finger, which receives a slight spark of – E, just before contact takes place; and after the finger is removed, the cover, when lifted by its insulating handle, gives a brisk spark of + E to anything presented to it. This can be repeated for several minutes without any apparent exhaustion of the source of electricity; and in dry weather, sparks can be got in this way hours, and frequently days, after the cake has been beaten.

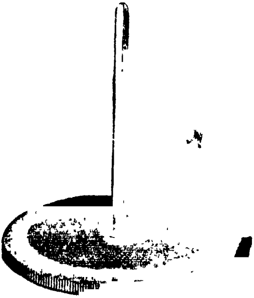


Fig. 60

The action of the electrophorus may be thus accounted for. When the surface of the cake of shell-lac is beaten, the friction excites – E on it. This acts inductively all round, but the tin mould being the nearest conductor, and shell-lac a good dielectric, the induction becomes concentrated on it, + E becoming fixed on the side next the shell-lac, and – E being sent to the ground. The – E of the upper surface of the shell-lac is thus fixed by the + E of the mould. When the cover is put on the cake, the contact between the two is not sufficient to allow the latter to communicate its charge to the former. The cover is thus acted on inductively, not conductively. The – E of the cake, then, has the choice of two channels for its induction, either through the cake to the mould, or through a very thin film of air to the cover. The latter, from its offering so short a passage through the dielectric, has the preference, and the inductive action of the charge is diverted from the mould to the cover, and the + E on the other side of the cake is for the time liberated and lost in the ground. The cover being strongly polarised, + E is induced and fixed on its lower surface, and – E on its upper, this last being transmitted to the ground by the finger. When the finger is withdrawn, and then the cover, the + E of the latter is free to discharge itself by spark, and inductive action again takes the direction of the mould, once more attracting + E to it. If the cover be lifted off without being touched, no spark can be got from it, as both induced electricities again unite. The induced polarity of the cover is attended with no loss to the charge of the shell-lac, which can thus continue to act with the same efficiency. The loss of electricity that all charged bodies experience in air, and especially when moist, at length discharges the cake, but this takes place all the less readily, that when the electricity is not needed to act on the cover, it is kept bound by the + E induced by it in the mould. In order that the + E of the mould should have liberty, so to speak, to come and go, the electrophorus must not be insulated; and when it is so, the action on the cover is feeble, if at all perceptible.

Atmospheric Electricity.

53. *Lightning* (Fr. *éclair*, Ger. *Blitz*).—Franklin was the first to establish the identity of the lightning of the heavens with the electric spark. By his famous kite experiment, he ascertained that the thunder-cloud assumes an electric condition precisely similar to that of the conductor of an electric machine, and that the same mechanical and luminous effects are common, though in a different degree to both. Clouds charged with electricity are called thunder-clouds, and are easily known by their peculiarly dark and dense appearance. The height of thunder-clouds is very various: sometimes they have been seen as high as 25,700 feet, and a thunder-cloud is recorded whose height was only 89 feet above the ground. According to Arago, there are three kinds of lightning, which he names lightning of the first, second, and third classes. Lightning of the first class is familiarly known as forked-lightning (Fr. *éclair en zig-zag*). It appears as a broken line of light, dense, thin, and well defined at the edges. Occasionally when darting between the clouds and the earth, it breaks up near the latter into two or three forks, and is then called bifurcate or trifurcate. The terminations of these branches are sometimes several thousand feet from each other. On several occasions, the length of forked-lightning has been tried to be got at trigonometrically, and the result gave a length of several miles. Lightning of the second class is what is commonly called sheet-lightning (Ger. *Flachenblitz*). It has no definite form, but seems to be a great mass of light. It has not the intensity of lightning of the first class. Sometimes it is tinged decidedly red, at other times, blue or violet. When it occurs behind a cloud, it lights up its outline only. Occasionally, it illumines the world of clouds, and appears to come forth from the heart of them. Sheet-lightning is very much more frequent than forked-lightning. Lightning of the third kind is called ball-lightning (Fr. *globes de feu*, Ger. *Kugelblitz*). This so-called lightning describes, perhaps, more a meteor, which, on rare occasions, accompanies

discharge, or lightning proper, than a phenomenon in itself electric. It is said to occur in this way: After a violent explosion of lightning, a ball is seen to proceed from the region of the explosion, and to make its way to the earth in a curved line like a bomb. When it reaches the ground, it either splits up at once, and disappears, or it rebounds like an elastic ball several times before doing so. It is described as being very dangerous, readily setting fire to the building on which it alights; and a lightning-conductor is no protection against it. Ball-lightning lasts for several seconds, and, in this respect, differs very widely from lightning of the first and second classes, which are, in the strictest sense, momentary.

The thunder (Fr. *tonnerre*, Ger. *Donner*) which accompanies lightning, as well as the snap attending the electric spark, has not yet been satisfactorily accounted for. Both, no doubt, arise from a commotion of the air brought about by the passage of electricity; but it is difficult to understand how it takes place. Suppose this difficulty cleared, there still remains the prolonged rolling of the thunder, and its strange rising and falling to account for. The echoes sent between the clouds and the earth, or between objects on the earth's surface, may explain this to some extent, but not fully. A person in the immediate neighbourhood of a flash of lightning hears only one sharp report, which is peculiarly sharp when an object is struck by it. A person at a distance hears the same report as a prolonged peal, and persons in different situations hear it each in a different way. This may be so far explained. The path of the lightning may be reckoned at one or two miles in length, and each point of the path is the origin of a separate sound. Suppose, for the sake of simplicity, that the path is a straight line, a person at the extremity of this line must hear a prolonged report; for though the sound originating at each point of the path is produced at the same instant, it is some time before the sound coming from the more distant points of the line reaches the ear. A person near the middle of the line hears the whole less prolonged, because he is more equidistant from the different parts of it. Each listener in this way hears a different [illegible], according to the position he stands in with reference to the line. On this supposition, however, thunder ought to begin at its loudest, and gradually die away, because the sound comes first from the nearest points, and then from points more and more distant. Such, however, it is well known, is not the case. Distant thunder at the beginning is just audible, and no more; then it gradually swells into a crashing sound, and again grows fainter, till it ceases. The rise and fall are not continuous, for the whole peal appears to be made up of several successive peals, which rise and fall as the whole. Some have attempted to account for this modulation from the forked form of the lightning, which makes so many different centres of sound, at different angles with each other, the waves coming from which interfere with each other, at one time moving in opposite directions, and obliterating the sound, at another in the same way, and then strengthening the sound, produced by each. Thunder has never been heard more than 14 miles from the flash. The report of artillery has been heard at much greater distances. It is said that the cannonading at the battle of Waterloo was heard at the town of Creil, in the north of France, about 115 miles from the field.

54. *Ordinary Weather.*—The attention that was first directed by Franklin's discovery to the atmospheric electricity, as displayed in the thunder-cloud, has since then been extended to the electrical condition of the air in all the different states of the weather. It is now found that the air is sensibly electrical not only when the sky is overcast with thunder-clouds, but when the weather is clear, or when no thunder-clouds are present. The observations of atmospheric electricity, in the latter circumstances, are made by means of very delicate electroscopes. These instruments are constructed for being used either alone in the open air, or in a room, in conjunction with an apparatus on the roof of the house for collecting the electricity. The following are some of the results derived from these observations: When the sky is clear and free from clouds, the atmospheric electricity is always positive, and an electroscope exposed to the action of the air is charged with + E. On the other hand the electricity of the ground is found to be −. This was shewn in a very ingenious way by

Volta, who, by catching the fine spray of a fountain on the plate of a straw electroscope, found the straws to diverge with the − E communicated to them by the water, which was necessarily of the same character as that of the ground. It is from this fact that electroscopes, or the collecting apparatus connected with them, must not be overtopped by the neighbouring trees or buildings, the − E of which materially affects the indications given, and it is due to the same fact that no atmospheric electricity is discovered in the middle of a wood, or in a room, however high the ceiling. Under a clear sky, the tension of the atmospheric electricity is found to increase as we ascend, the lower aërial strata being less electrical than the higher. Becquerel proved this by a simple experiment on the plateau of Mount St Bernard. On a piece of oiled silk he placed a silk thread, covered with tinsel, one end of which, terminated by a ring, was connected with the rod of a straw electroscope, and the other end was tied to an arrow armed with a metal point. When the arrow was shot horizontally, the straws shewed no divergence; but when the arrow was shot upwards, they opened as it ascended, and diverged most when the arrow, in ascending, disengaged the ring from the rod of the electroscope. The same fact is shewn in the following way: When a very delicate electroscope is adjusted for any particular position, it will, when elevated a few feet above that position, give indication of + E, and when placed a few feet below, it will be charged negatively. In clear weather, likewise, the atmospheric electricity is found to be subject to certain daily periodical variations, and appears to have two maxima and two minima in the course of twenty-four hours. The first maximum takes place a short time after sunrise, and the second shortly after sunset; the first minimum shortly before sunrise, and the second in the afternoon, when the heat of the day is greatest. The cause of these periodical changes is attributed to the formation and condensation of watery vapour in the atmosphere; shortly after sunrise, a vast quantity of vapour rises into the lower stratum of the air, and acting as a conductor, transmits the electricity of the higher strata towards the surface of the earth, giving rise to the first maximum. As the heat of the day increases, the air becomes less and less moist, and loses, in consequence, its conducting power, so that when the atmosphere is hottest and driest, the afternoon minimum takes place. After sunset, a rapid condensation occurs, and the lower strata are once more charged with moisture, which causes a second maximum at the beginning of night. Before sunrise, the deposition of dew becomes greatest, so that the + E of the lower strata is transmitted to the soil, causing a minimum at that time. It seems to hold generally that anything which tends to increase the conducting power of the lower strata, such as watery vapour in a visible form, increases at the same time the atmospheric electricity, and hence it is that in time of mist the electrical tension is higher than in clear weather. It may also be attributed to the same fact that the atmospheric electricity is greatest in January, and least in June, the former month being cold and misty, and the latter warm and clear. In cloudy weather, the electroscope is affected sometimes positively, sometimes negatively, and is generally less influenced than in clear weather. The electricity of rain, snow, hail, &c., is sometimes positive, sometimes negative. In Stuttgart, for instance, it was found in the course of a year that the rain was 71 times positive to 69 times negative, and the snow 24 times positive to 6 times negative.

The cause of atmospheric electricity has given rise to much discussion among meteorologists, and as yet no theory has been proposed which satisfactorily accounts for it. According to Pouillet's theory, the electricity developed in evaporation and vegetation is a sufficient cause for the + E of the air; the vapours and gases evolved in these processes being charged positively, the soil and plants, on the other hand, negatively. This opinion is combated by more recent observers, such as Riess and Reich, who, after a series of careful experiments, give it as their opinion that if such be the cause of atmospheric electricity, the fact is wholly without experimental data. Lamont maintains that the air itself is not electrical, and is not capable either of conducting or of retaining electricity, and that the phenomenon of atmospheric electricity is due to the induction arising from the − E of the earth, which he considers to be permanent.

55. *Lightning-Conductors* (Fr. *paratonnerre*, Ger. *Blitzableiter*).—The principle of the lightning-conductor is, that electricity, of two conducting passages, selects the better; and that when it has got a sufficient conducting passage, it is disarmed of all destructive energy. If a person holds his hand near the prime conductor of a powerful electric machine in action, he receives long forked stinging sparks, each of which causes a very sensible convulsion in his frame. But if he holds in his hand a ball connected with the ground by a wire or chain, the above sensation is scarcely, if at all, felt, as each spark occurs, for the electricity, now having the ball and wire passage to the ground, prefers it to the less conducting body. If, instead of a ball, a pointed rod were used, no sparks would pass, and no sensation whatever would be felt. The point silently discharges the prime conductor, and does not allow the electricity to accumulate in it so as to produce a spark; and the quantity passing at a time, even supposing the rod disconnected with the ground, is not sufficient to affect the nerves. If, for the prime conductor of the machine, we substitute the thunder-clouds; for the body, a building; for the convulsive sensation, as the evidence of electric power, heating and other destructive effects; for the ball, or rod, and wire, the lightning-conductor, we have the same conditions exhibited on a larger natural scale. It is easier, however, to protect a building from the attacks of lightning than the body from the electric spark, as the rod in the one case is a much better conductor, compared with the building, than it is compared with the body, and in consequence more easily diverts the electricity into it.

The lightning-conductor consists of three parts: the rod, or part overtopping the building; the conductor, or part connecting the rod with the ground; and the part in the ground. The rod is made of a pyramidal or conical form (the latter being preferable), from 8 to 30 feet in height, securely fixed to the roof or highest part of the building. Gay-Lussac proposes that this rod should consist, for the greater part of its length below, of iron; that it should then be surmounted by a short sharp cone of brass; and that it should finally end in a fine platinum needle; the whole being riveted or soldered together, so as to render perfect the conducting connection of the parts. The difficulty of constructing such a rod has led generally to the adoption of simple rods of iron or copper, whose points are gilt, to keep them from becoming blunt by oxidation. It is of the utmost importance that the upper extremity of the rod should end in a sharp point, because the sharper the point the more is the electrical action of the conductor limited to the point, and diverted from the rest of the conductor. There is thus less danger of the electricity sparking from the conductor at the side of the building into the building itself. Were the quantity of the electricity of the clouds not so enormous, the pointed rod would prevent a lightning-discharge altogether; but even as it is, the violence of the lightning-discharge is considerably lessened by the silent discharging-power of the point previously taking place. According to Eisenlohr, a conical rod, 8 feet in height, ought to have a diameter at its base of 13.3 lines, and one of 30 feet a diameter of 26.6 lines.

The part of the lightning-conductor forming the connection between the rod and the ground, is generally a prismatic or cylindrical rod of iron (the latter being preferable), or a strap of copper; sometimes a rope of iron or copper wire is used. Iron wire improves as a conductor when electric currents pass through it; copper wire, in the same circumstances, becomes brittle. An iron rope is much better, therefore, for conducting than a copper one. Galvanised iron is, of all materials, the best for conductors. The conducting-rod ought to be properly connected with the conical rod either by riveting or soldering or both. Here, as at every point of juncture, the utmost care must be taken that there is no break in the conduction. The conducting-rod is led along the roof, and down the outside of the walls, and is kept in its position by holdfasts fixed in the building. There must be no sharp turns in it, but each bend must be made as round as possible. Considerable discussion has arisen as to the proper thickness for the conducting-rod. If it were too small, it would only conduct part of the electricity, and leave the building to conduct the rest, and it might be melted by the electricity endeavouring to force a passage through it as an insufficient conductor. The Paris Commission, which sat in 1823, gave the minimum section of an iron conductor as a square of 15 millimètres (about $\frac{3}{5}$ths of an inch) in side, and this they considered quite sufficient in all circumstances. A rod of copper would need to be only $\frac{2}{5}$ths of this, as copper conducts electricity about six times more readily than iron. This calculation is very generally followed in practice. In leading the conductor along the building, it should be kept as much apart as possible from masses of conducting matter about the building, such as iron beams, machinery, &c. These may form a broken chain of conductors communicating with the ground, and divert a portion of the electricity from the lightning-conductor. If such took place, then at each interruption electricity would pass in a visible and dangerous way, and the efficacy of the conductor would be lost. If the conductor cannot be properly insulated from these masses of metal, the necessary security is got by putting them in connection with the conductor, so as to form a part of it. Water-runs, leaden roofs, and the like, must, for this reason, all be placed in conducting connection with the conductor.

The portion of the lightning-conductor which is placed on the ground is no less worthy of attention than the other two. Should the lower part of the conductor end in dry earth, it is worse than useless, for when the lightning, attracted by the prominence and point of the upper rod, strikes it, it finds, in all likelihood, no passage through the unconducting dry earth, and, in consequence, strikes off to a part of the ground where it may easily disperse itself and be lost. Wherever it is practicable, a lightning-conductor should end in a well or large body of water. Water is a good conductor, and having various ramifications in the soil, offers the best facility to the electricity to become dispersed and harmless in the ground. The rod, on reaching the ground, should be led down a foot and a half, or two feet, into the soil, and then turned away at right angles to the wall from the building in a horizontal drain filled with charcoal, for about from 12 to 16 feet, and then turned into the well so far that its termination is little likely to be left dry. Where a well cannot be made, a hole 6 inches wide (wider if possible) should be bored, from 9 to

16 feet, the rod placed in the middle of it, and the intervening space closely packed with freshly-heated charcoal. The charcoal serves the double purpose of keeping the iron from rusting, and of leading away the electricity from the rod into the ground.

Lightning-conductors, when constructed with care, have been proved beyond a doubt to be a sufficient protection from the ravages of lightning. The circle within which a lightning-conductor is found to be efficacious, is very limited. Its radius is generally assumed to be twice the height of the rod. On large buildings, it is therefore necessary to have several rods, one on each prominent part of the building, all being connected so as to form one conducting system. In ships, a rod is placed on every mast, and their connection with the sea is established by strips of copper inlaid in the masts, and attached below to the metal of or about the keel.

Chronology of Frictional Electricity.

56. Thales, about 600 B.C., refers in his writings to the fact that amber, when rubbed, attracts light and dry bodies. This was the only electric fact known to the ancients. The science of electricity dates properly from the year 1600 A.D., when Gilbert of Colchester published his celebrated treatise (23), in which he gives a list of substances which he found to possess the same property as amber, and speculates on magnetic and electric forces. He is the inventor of the word electricity, which he derived from the Greek word *electron*, amber. Otto von Guericke, burgomaster of Magdeburg, in his work *Experimenta Nova Magdeburdica* (1672), describes, among his other inventions, the first electric machine ever made, which consisted of a globe of sulphur turned by a handle, and rubbed by a cloth pressed against it by the hand. Hawksbee (1709) constructed a machine in which a glass cylinder, rubbed by the dry hand, replaced Guericke's sulphur globe. Grey and Wehler (1729) were the first to transmit electricity from one point to another, and to distinguish bodies into conductors

and non-conductors. Dufay (1733—1745) shewed the identity of electrics and non-conductors, and of non-electrics and conductors, and was the first to discover the two kinds of electricity, and the fundamental principle which regulates their action. Between the years 1733 and 1744, much attention was given in Germany to the construction of electric machines. Up to this time, notwithstanding the inventions of Guericke and Hawksbee, the glass tube rubbed by a piece of cloth which Gilbert first introduced, was used in all experiments. Boze, a professor at Wittenberg, taking the hint from Hawksbee's machine, employed a globe of glass for his machine, and furnished it with a prime conductor. Winkler, a professor at Leipsic, was the first to use a fixed cushion in the machine. The Leyden jar was (1746) discovered accidentally at Leyden by Muschenbroek ; but the honour of the discovery has been contested also in favour of Cuneus, a rich burgess of that town, and Kleist, canon of the cathedral of Camin, in Pomerania. Franklin (1747) shewed the electric conditions of the Leyden jar, and (1752) proved the identity of lightning and electricity by his famous kite experiment. This last was performed with the same object about the same time, and quite independently, by Romas of the town of Nerac, in France. In 1760, Franklin made the first lightning-conductor. Canton, Wilke, and Æpinus (1753—1759), examined the nature of induction. Ramsden (1768) was the first to construct a plate-machine, and Nairn (1780) a two fluid cylinder-machine. The electrophorus was invented by Volta in 1775, and the condenser by the same electrician in 1782. In 1787, Coulomb, by means of his torsion-balance, investigated the laws of electric attraction and repulsion. In 1837, Faraday published the first of his researches on induction. Armstrong, in 1840, designed his hydro-electric machine.

GALVANISM.

57. *Galvanism*, or *Voltaic Electricity*, is that branch of the science of electricity which treats of the electric currents arising from chemical action, more particularly from that attending the dissolution of metals. It is sometimes called Dynamical Electricity, because it deals with current electricity, or electricity in motion, and is thus distinguished from Frictional Electricity, which is called Statical, in consequence of its investigating the electric condition of bodies in which electricity remains insulated or stationary. These terms, although in the main thus properly applied, are in all strictness applicable to both sciences. Frictional electricity, though small in quantity, can pass in a sensible current, and galvanic electricity, though small in tension, can be made to manifest the attractions and repulsions of statical electricity. Thus the series of discharges which are transmitted in a wire connecting the prime conductor of a machine in action with the ground, or negative conductor, possesses, though feebly, the characteristics of a galvanic current, and the insulated poles of a many-celled galvanic battery, manifest before the current begins the electric tension of the friction machine. The other sources of current electricity will be treated under Magneto-electricity and Thermo-electricity.

Action of Galvanic Pair, or Single Cell.

58. *Galvanic* or *Voltaic Pair.*—When two plates of copper and amalgamated zinc (zinc whose surface has been rubbed over with mercury) are placed in a vessel (fig. 61) containing water to which a small quantity of sulphuric acid has been added, so long as they are kept from touching, either within or without the liquid, they remain apparently unaffected. If,

however, they be made to touch, bubbles of hydrogen gas are formed in abundance at the copper plate, and their formation continues until the plates are again separated. If the contact be maintained for some time, and the plates and liquid be afterwards examined, it is found that the copper plate weighs

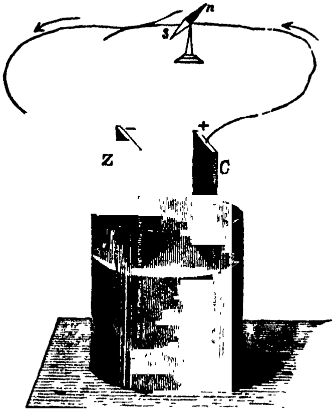


Fig. 61.

exactly the same as before, that the zinc plate has lost in weight, and that the liquid contains the lost zinc in solution in the form of the sulphate of that metal. The contact need not be affected by the plates themselves. If wires of copper, or any other conductor of electricity, be soldered to the plates, or fixed to them by binding screws, and be made to touch, the changes just mentioned take place as if the plates were in contact. When the wires are thus joined, and, so to speak, form one connecting wire between the plates, they exhibit very peculiar properties. If a portion of the connecting wire be placed parallel to a magnetic needle, and the needle brought near, its north end no longer points to the magnetic north, but to a point either to the east or west of it, and this deviation ceases with the separation of the wires. It is not even necessary that the wires be in contact, for if their ends be put into a vessel containing a conducting liquid, the same changes occur, though to a diminished extent, the contact being completed through the liquid. The ends of the wires, when so immersed, shew strong chemical affinities. If the conducting liquid were a solution of the sulphate of copper, the wire from the zinc becomes coated with the copper of the solution, whilst the other attracts its oxygen and sulphuric acid, and wastes away in entering into combination with them. Again, if the ends of the wires be connected by a small piece of fine platinum or iron wire, the passage of the current through it will make it red hot. The connecting wires are found, therefore, in actual or virtual combination, to possess very marked magnetic, chemical, and heating properties. The arrangement just described constitutes a *galvanic or voltaic pair*, which generally consists of *two dissimilar conducting plates immersed in a liquid which acts chemically on one of them, when the plates are put in conducting connection;* and the properties just referred to, form the characteristic powers of current electricity.

59. *Effects of the Galvanic Pair due to Electricity in Current.*—These properties arise from the wires in connection being the seat of a constant discharge or flow of electricity, for they are possessed, though to a very feeble extent, by the electricity of the friction electric machine. If the prime conductor of a powerful electric machine be connected with one of the binding screws of an insulated galvanometer, and a wire connected with the ground, or the negative conductor, be fixed into the other, the plate on being turned causes a current of electricity to pass from the machine to the ground through the coil of the galvanometer, the needle of which will then shew a deviation of one or two degrees. The deviation, so far as direction is concerned, is the same as that which would be produced by placing the wires coming from the copper and zinc respectively in the same binding screws as those connected with the machine and the ground. This would indicate that the copper plate stands electrically in the same relation to the zinc plate as the prime conductor of the machine to the ground. The electricity of the conductor is positive, and that of the ground by induction negative; so

that in the galvanic pair the copper plate, by analogy, gives off + E, and the zinc plate –. Again, let the wire from the machine end in an insulated vessel containing a solution of the sulphate of copper, and let the end of a fine platinum wire connected with the ground be made to dip below the surface of the solution, and let the machine be kept in action so as to send a current of electricity through the wires and liquid, at the end of some minutes the point of the platinum wire will be covered with a minute quantity of copper. The wire connected with the zinc in the galvanic pair, and that connected with the ground, are thus shewn to display the same chemical power; and this, again, shews us that the zinc plate, like the ground in the above experiment, is the seat of – E. The electric condition of the plates before contact reveals, with the aid of the condenser, the presence of + E in the copper plate and – in the zinc plate. If the wire joined to the zinc plate be connected with the ground, and the insulated wire connected with the copper be made to touch the lower plate of a condenser whilst the finger touches the upper, on the finger being first withdrawn, then the wire and the upper plate lifted up from the lower, the leaves of the electroscope diverge with the + E sent to it from the copper plate.

It can be shewn, moreover, that the current is not confined to the connecting wire, for if a magnetic needle be suspended between the plates when they lie north and south, slightly above the surface of the liquid, it will deviate from its usual position when the wires are joined, and in the opposite way to that which it shews when held above the wire placed in the same direction. The current thus passes within the liquid from the zinc to the copper the opposite way to that in which it runs in the connecting wires, so that it makes a complete circuit. Hence we may conclude, generally, that *in the galvanic pair a current of electricity runs within the liquid from the chemically active to the chemically passive plate, and without the liquid, from the chemically passive to the chemically active plate, making a complete circuit;* and that if the conducting connection be interrupted, the pair shews electric polarity at the interruption, the *chemically passive plate being the positive* *pole, and the chemically active plate the negative pole.* With respect to *the liquid,* however, *the chemical active plate is the positive pole, and the chemically passive the negative pole.*

60. The galvanic pair in action exhibits a complete electric circle or chain, and constitutes what is called a galvanic or voltaic *circuit* (Ger. *galvanische Kette*). When the circuit includes only one pair or cell, it is called a *simple galvanic circuit,* when several joined together alternately, a *compound galvanic circuit.* The compound circuit will be treated under galvanic battery. When the metallic connection between the plates is complete, and the current flows or circulates, the circuit is said to be *closed* (Fr. *fermé*, Ger. *geschlossen*); when incomplete, and the current stops, *opened* or *interrupted* (Fr. *interrompu,* Ger. *geöffnet*).

61. *Circuit with two liquids and one metal.*—We have other ways of producing a simple galvanic circuit than by the employment of two metals and one liquid as in the galvanic pair. Two liquids and one metal can also produce a circuit. One of the best known arrangements of this kind is Becquerel's so-called oxygen battery (*pile à oxygène*), in which a current is produced by the action of caustic potash on nitric acid—platinum, a metal acted upon by neither, forming the conducting arc. The cell, fig. 62, shews its mode of action. A small cell, A, of porous earthenware is suspended by a wire triangle within a glass jar, BB. The porous cell contains a solution of caustic potash, and the glass jar concentrated nitric acid. A plate of platinum, P, is put into each vessel, to which the wires of a galvanometer are attached. The potash and nitric acid act on each other in the walls of the porous cell, forming saltpetre, and produce a current lasting steadily for days, which flows from the potash to the nitric acid, and from the plate in the nitric acid through the wires to that in the potash. Oxygen is

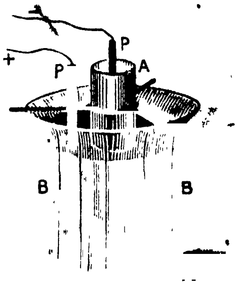


Fig. 62.

given off at the potash plate. The nitric acid plate is the +, and the potash plate the – pole. A similar result takes place in many cases when the other soluble bases are substituted for potash, and another acid for nitric acid, the current observing the same direction, though differing in intensity. Matteucci substituted penta-sulphide of potassium for caustic potash in the inner cell, and put either nitric acid or chromic acid in the outer, and thereby produced a much stronger current than in Becquerel's arrangement.

In the preceding circuit, the metal conductor suffers no change, and seems to take no part in the action other than acting as conductor. In other circuits with two liquids and one metal, the metal takes an active part. A circuit of this kind may be formed by putting a solution of chloride of sodium (common salt) in the inner cell, and one of chloride of copper in the outer cell, in place of potash and nitric acid, and bending a strip of copper so as to dip into both. A weak but steady current flows in the same direction as before, attended by the corrosion of the end of the strip immersed in the solution of chloride of sodium, and a deposition of crystals of copper on the end dipping into the chloride of copper. In the former case the action appears to arise from the affinity of the base for the acid, and in the present case from the affinity of the copper for the chlorine of the common salt. Other circuits may be mentioned, such as the circuit consisting of two metals and two liquids, and also that of two gases, a metal and a liquid. The former of these, which is essentially the same as that of two metals and one liquid, and the latter, which is known as the gas-battery, will be described under the various forms of the galvanic battery.

62. *The theory of the action of the galvanic pair* may be thus given. When the two plates are put into the water and sulphuric acid they assume opposite electric states. There is developed at the surface of the zinc an electric force, arising from its affinity for the oxygen of the water, which throws the whole arrangement into a state of polarity. This is roughly shewn in fig. 63. The zinc plate with its wire becomes polarised, shewing – E at the extremity furthest from the liquid, and + E at

the extremity next the liquid. The copper plate with its wire is polarised in the opposite way, being + at its outer end, and – at its end next the liquid. The compound molecules of water (H_2O), consisting of one atom of oxygen (O) and two of hydrogen (H_2) so united as to play the part of one atom or molecule (shewn by H in the figure). It appears, moreover, to have reference to their compound nature, and we may imagine them placed in series such as the one in the figure, with their oxygen or – pole towards the zinc, and their hydrogen or + pole towards the copper. The + parts are distinguished from the – parts in the figure by being shaded. When the ends of the wires are brought near each other, we might anticipate in these circumstances that a spark discharge, as with frictional electricity, would restore quiescence. This, however, is not the case, for the electric tension is so low that nothing short of contact can effect a discharge. When the discharge thus takes place, the polarity of the circuit for the instant ceases; the tendency to union of the zinc with the atom of oxygen next it is completed by the formation of the oxide of zinc. But in order to accomplish this, the hydrogen of the molecule of water next the zinc thus set free unites with the oxygen of the neighbouring molecule to re-form water, and the same transference and union is

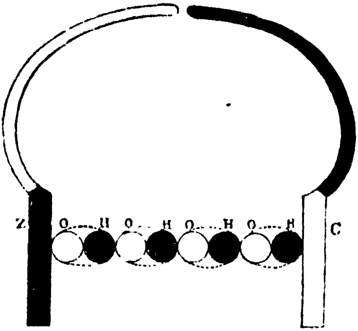


Fig 63.

continued along the whole series until the hydrogen of the molecule next the copper is thrown on the copper, where, being unable to unite chemically with it, it assumes its natural gaseous state. In this way the chemical action, although only manifested at the plates, is not confined to them, but takes place throughout the liquid between all the contiguous molecules giving passage to the current. The oxide of zinc formed on the zinc plate is instantly dissolved by the sulphuric acid present in the water, leaving the plate as clean as before. After the first discharge, therefore, the whole arrangement resumes its first condition, so that a second polarisation and discharge instantly follows, which is succeeded by a third, and so on. An uninterrupted series of discharges, following each other with inconceivable rapidity, is thus transmitted along the completed circuit, constituting what is termed a current of electricity.

For the sake of simplicity, we have here looked upon the water as the active chemical agent in the galvanic pair. Pure water, no doubt, does produce a current when so placed, but of excessively feeble intensity. It is only when sulphuric acid is added that the current acquires anything like strength. Hence it is thought more probable that it is the sulphuric acid which gives rise to the action, and that the water serves to dissolve the sulphate of zinc formed on the zinc plate, both water and sulphuric acid being necessary to steady action. According to this view, we best understand the action of sulphuric acid by considering the mono-hydrated acid, H_2O,SO_3, to be H_2SO_4, composed of a two-atom molecule of hydrogen and a molecule of sulphion, SO_4, consisting of one atom of sulphur and four of oxygen. In the preceding diagram, we have only to suppose the simple molecule marked O to be a compound molecule, SO_4, and we have an equally simple and more probable view of the action of the pair. We may express these views also conveniently by equations representing each molecule by its chemical symbol. According to the first, before discharge they would be thus arranged, Zn, $\overline{OH_2}$ $\overline{OH_2}$ $\overline{OH_2}$ $\overline{OH_2}$, Cu ; after discharge, thus, $\overline{ZnO}$ $\overline{H_2O}$ $\overline{H_2O}$ $\overline{H_2O}$ H_2,Cu ; the strokes above shewing how they are united in each case. According to the second view,

before discharge, $Zn,\ \overline{SO_4,H_2}\ \overline{SO_4,H_2}\ \overline{SO_4,H_2}\ \overline{SO_4,H_2},\ Cu$;
after discharge, $\overline{Zn,SO_4}\ \overline{H_2,SO_4}\ \overline{H_2,SO_4}\ \overline{H_2,SO_4}\ H_2,Cu$.

63. *Homogeneity of the Circuit.*—In a wire where a current of electricity is circulating, there is no point which forms, as in frictional electricity, the seat of + or − E, but it appears electrically homogeneous throughout. It exerts no statical inductive action on surrounding objects; that is, it has no power, like insulated electricity, to attract and repel light objects. The wire in which the current is passing may be handled, and it feels in no way different when the current is passing and when it is not. The absence of statical induction, however, depends solely on the facility which the wire offers to the passage of the electric force as compared with surrounding media, as is shewn by the leaping across of the frictional electricity at the bend of the wire mentioned in article 34, fig. 38. Galvanic electricity, even from a large battery, however, can seldom do this, and except in long telegraphic circuits, where the resistance is very great, docilely follows its metallic passage, to it by far the easiest. But even in the divided circuit of fig. 38, if the force passing through the air and the long wire be added together, it will be found exactly equal in amount to that passing in the wires before the branching takes place. Returning to the simple galvanic circuit, we find that it exhibits the same amount of force at every point. Its magnetic, chemical, and heating effects are the same wherever it is tested, whether in the wire or, where possible, in the liquid. Its power to deflect the magnetic needle is throughout the same. If interruptions be made in the interpolar wire at several points so as to send the current through solutions, say of sulphate of copper, the amount of copper deposited at each of the breaks is exactly equal in amount. And if we connect the several breaks by pieces of thin platinum wire, each piece of platinum wire will be raised to the same temperature.

64. *Polarity of the Circuit.*—Any portion of the circuit, separately considered, has a different pole at each end. When one interruption is made, as in fig. 63, the whole, from the extremity of the wire connected with the copper, round to that of the wire joined to the zinc, may be looked upon as

one. It may be shewn by the condensing electroscope (51) that each extremity has an opposite electricity. If we break away any portion of either wire so as to have two breaks instead of one, the piece of wire broken away is out of the circuit altogether. However, by dipping the ends of the wires at each interruption into a liquid that is decomposed under the current, we have the means of making two such interruptions without destroying the conducting connection or stopping the current. Fig. 64 shews how this may be done A and B are two vessels filled with a solution of sulphate of copper (Cu,SO_4). The end of the copper wire soldered to the zinc-plate Z of the galvanic pair CZ dips into A, that from the copper-plate C dips into B, and the ends of the wire broken off dip the one into A and the other into B. The circuit is thus closed. In it we have three metallic parts marked 1, 2, and 3. The part 1, which is made up of the zinc-plate and copper-wire, is corroded at the end marked + in the liquid of the galvanic pair, and receives a deposit of copper at the end marked —. The part 2 wastes away at the + end in A, but receives a deposit of copper at the — end in B; and the part 3 is likewise corroded at the + end in B, and receives, so to speak, a deposit of hydrogen at the — end in the liquid of the pair. Each part undergoes opposite operations at each end. We know (59) that the wire from the zinc is —, that from the copper +; and as we thus know the sign of two opposite poles, the others follow of course. Each + pole is here eaten away, and each — pole receives a deposit of copper. Each metallic portion of the circuit has a + pole at the one end and a — pole at the other. The polarity of the current we should not expect to be the same as the polarity of insulated frictional electricity, for the latter is that tending to discharge, whereas the former is that attending discharge; the one is, so to speak, statical, the other dynamical. Yet, in the case of galvanic polarity, we may trace the existence of something analogous to the

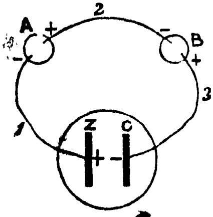


Fig. 64.

attraction and repulsion characteristic of statical polarity. Sulphuric acid, as already stated (62), is made up of a two-atom molecule of hydrogen (H_2), and a molecule of sulphion (SO_4). Similarly, sulphate of copper (Cu,SO_4) is composed of a molecule of copper (Cu) and one of sulphion (SO_4). The corrosion of the + poles arises in the above circuit to their affinity or attraction for SO_4. They appear to attract the molecule SO_4 of the combination Cu,SO_4 and H_2,SO_4, and reject the Cu and the H_2. The — poles have these affinities reversed. If we consider the SO_4 to be the — element of the combination, and H_2 and Cu the +, which cannot be otherwise, we have like electricities repelling and unlike electricities attracting, as in frictional or statical electricity. Such being the case, the liquid portions of the circuit, like the solid, are + at the one end and — at the other, but in the reverse way. The circuit, therefore, is made up throughout of + following —, and — following +. Considerable confusion sometimes arises from speaking of the zinc plate as at once the + element and — pole, and the copper the — element and + pole of the galvanic pair, and such expressions seem even inconsistent. The truth is, that the zinc and copper plates must have each both poles from the very nature of the circuit; but as the outer poles only of these plates are of practical importance, these are considered to be the poles. If we need a mnemonic, the *n* in zinc, which is almost always associated in the pair as the + element, cannot fail to remind us that it is the — pole.

65. *Theoretical Views of the Current.*—According to the one-fluid theory of electricity, a force is developed at the seat of the action, which has the power of liberating the electric fluid, and of maintaining it in motion throughout the circuit, constituting a current in the true sense of the term. According to the two-fluid theory, two such currents, one of the + the other of the — fluid, are made to move in opposite directions throughout the circuit. Neither of these explanations gives us any assistance in comprehending the current. It is more difficult, in fact, to conceive of such currents than to accept, without any explanation, the known characteristics of the so-called current. According to the views taken of the

propagation of electric force by molecular action (32 and 33), we may consider the molecules of the interpolar wire to be as shewn in fig. 65, C being the copper end and Z the zinc end, the shaded parts being + and the unshaded —. The first effort of the electric force developed by the chemical affinity of the zinc for the O or SO_4, is to throw all the molecules of the circuit into a polar condition, the force being transmitted from molecule to molecule in both directions. + and — electricities appear in each molecule of the circuit; and if the action be powerful enough, discharge takes place throughout the whole, each molecule giving out its electricities to those next it, which, throwing out the opposite electricities, produce electric quiescence throughout. A constant series of such polarisations and discharges constitutes a current. There is thus only a transmission of force throughout the circuit, but no transmission of the + and — electricities. Each molecule, in fact, may be looked upon as a small galvanic pair, which, by the action of electric force, is made to act and discharge somewhat like the galvanic pair, which is the seat of the force. Accordingly, whatever portion of the circuit without the liquid we take, such as that in the figure, we find the face of the terminal molecule next the copper end or pole —, and that of the like molecule towards the zinc +. Each portion of the circuit, like each molecule of which it is made up, shews opposite polarities, and discharges opposite electricities at each end. The same holds within the liquid, only the chemical affinity that gives rise to the current and the mobility of its molecules, causes and permits an interchange of molecules, just as if each half of the molecules in fig. 65 were at each discharge joined to the succeeding one. This interchange is not possible, even were there a tendency to it in the solid part of the circuit.

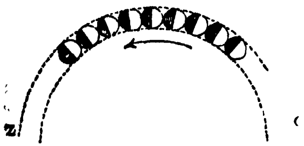


Fig. 65.

A current may be taken to signify, apart from all supposition, simply the peculiar electric condition of the conductor, which forms the line of discharge between a + and a —

source of electricity. In like manner, when we speak of the direction of the current, we only use a convenient way of shewing at which end the + and — electricities arise, *the current being always represented as moving from the + to the —.*

66. *Origin of Galvanic Electricity.*—It is now generally admitted that the *electro-motive force*, or force maintaining the current, in the galvanic pair, is the force of chemical affinity acting at the zinc plate. It must appear, even to the most cursory observer, highly probable that the seat of the most active change going forward in the pair is likewise the seat of its electric energy. It is found, moreover, when we tax the galvanic current with electro-chemical or dynamical work, that the amount of work done by it is exactly proportionate to the quantity of zinc dissolved. These and similar considerations seem to argue strongly that galvanic action has its source in chemical action. Volta, however, and several of the most eminent authorities in the science, maintain that the electro-motive force has its seat at the surface of contact of heterogeneous metals, and that chemical action is not the cause, but the manifestation of it. This view of the origin of galvanic electricity is called the *contact theory*, as distinguished from the *chemical theory*, the one we have hitherto followed.

67. *The Contact Theory* supposes that at the surfaces of contact of two heterogeneous substances an electro-motive force, invariable in direction and amount, is generated, and subject to modification only by the resistance offered by the conducting circuit. The galvanic pair (fig. 61) is accounted for by this theory in the following way. Let us suppose, for the sake of explanation, that both zinc and copper plates are connected by copper wires. The seat of electro-motive force is at the junction of the copper wire with the zinc. At this point the two metals assume opposite electricities, the copper the —, and the zinc the +; and since a conducting circuit through wires, plates, and liquid is established, these electricities travel in opposite directions, and, meeting, neutralise each other within the liquid, to give place to succeeding similar discharges of electricity. The discharge within the liquid takes place electrolytically. The theory is, in this case,

sufficient and consistent; but it must be kept in mind, that in a circuit so perfectly homogeneous, the source of force may be placed anywhere without altering its conditions. The fundamental evidence of the contact theory consists in an experiment like the following: A piece of zinc is made to touch the lower brass or copper plate of a condenser, while the finger rests on the upper. After the finger and the zinc are removed, and the upper plate lifted, the gold leaves diverge with — E. Here the mere contact of metals appears to give rise to electricity. The + E of the zinc goes to the ground, and the — E of the copper is insulated in it, the electro-motive force originating at the surface, where the copper and zinc meet. If this experiment were capable only of this interpretation, it would be decisive of the question at issue. It is found, however, that in order to succeed well with it the fingers must be moist, and that no electricity can be obtained if it be conducted in a gas where no free oxygen is present—such as nitrogen or carbonic acid. Hence it appears, that even in the testing experiment of the contact theory, where it is supposed that contact alone can give any explanation, chemical action, arising from the sweat of the fingers and oxygen of the air acting on the zinc, is present.

68. Faraday's experimental researches seem to place beyond dispute the *truth of the chemical theory*. We shall here quote two of his many beautiful experiments illustrative of the subject, which are of themselves quite convincing. Let (fig. 66) A and B be two glass vessels containing sulphuret of potassium. Two platinum plates, P and P′, are put into the vessel A, and an iron plate F, with a platinum plate P″ in B. To the platinum plate P′ a platinum wire *p*, and to the iron plate F an iron wire *f*, are attached. From P and P″, wires proceed to the

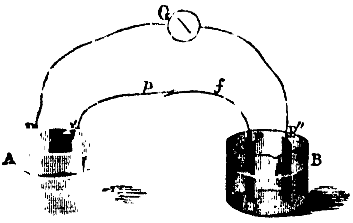


Fig. 66.

galvanometer G. The sulphuret of potassium is, for a liquid, a good conductor of electricity, but is chemically inactive when associated with platinum and iron in a circuit. When the wires *p* and *f* are joined, if an electro-motive force were developed at their surface of contact, all the conditions necessary for a circuit being present, a current would be generated, which would deflect the needle of the galvanometer. This last, however, gives not the slightest evidence of a current. If zinc be interposed at the junction of *p* and *f*, the galvanometer is equally unaffected; but if a piece of paper moistened with sulphuric acid be placed between the ends of these wires, a decided deflection ensues, and the iron becomes the positive element of a platinum-iron pair. We have thus conclusive evidence, that the simple contact of the iron and the platinum is unattended by electro-motive force, and that this is developed only by the chemical action upon the iron of an interposed liquid. Again, into one of the vessels just referred to, let two plates, one of copper, the other of silver, be placed, and let communication be established between them and the galvanometer. The needle at first deflects briskly in a direction which shews that the copper is the + element of the pair, it then gradually returns to its first position, and again deflects in the opposite direction, shewing that the silver is now the + element. After some time it returns, and again deflects in the original direction, and goes on thus changing. If the plates be examined during these changes, it is observed that sulphuret of copper is formed when the copper is +, and sulphuret of silver when the silver is +; the alternate action being attributable to the relative condition of the plates when coated with their sulphurets. The electro-motive force of a silver copper pair is thus shewn to be not invariable in direction as the contact theorists maintain; but to change its direction with the seat of chemical action.

69. *Chemical conditions of the Galvanic Pair.*—We have hitherto supposed that, in the galvanic pair, the zinc alone had affinity for the oxygen of the water, but chemistry teaches us that copper likewise has the same affinity, though to a less degree. Hence we must conclude that there originates at the

copper an electro-motive force acting contrary to that of the zinc, and that the electro-motive force of the pair is the difference of these opposing forces. Were we to take two similar plates of zinc, instead of one of zinc, and the other of copper, we should thus have two equal forces tending to propel two equal currents in opposite directions. In this case the two forces would equilibrate each other, and electrical and chemical inaction would be the consequence, a conclusion quite in keeping with experiment. It therefore becomes necessary to couple the zinc with a metal such as copper, less oxidable than itself. In keeping with this theory, it is found that if the zinc be coupled with a metal less oxidable still than copper, the resultant electro-motive force is increased. A pair consisting of zinc and silver gives an electricity of higher tension, and consequently a more powerful current than one of zinc and copper, and one of zinc and platinum a stronger current still; silver being less oxidable than copper, and platinum less than silver. The greater, then, the disparity in oxidability, or in liability to be affected by the exciting liquid of the metals of the pair, the greater is its power.

70. *Electro-chemical Order of the Elements* (Ger. on the contact theory, *Spannungsreihe*).—In the galvanic cell we find that not only the metals, but also the elements, of the liquid assume opposite electricities. Within the liquid the zinc is + and the copper −, the oxygen + and the hydrogen −. The elements have been arranged electro-chemically approximately to the part they play if associated in the galvanic pair. We may here give the more common elements thus arranged, beginning with the most electro-positive, and ending with the least positive or negative—the arrow marking the direction of the current within the cell.

→

+ Potassium. Sodium. Magnesium. Zinc. Iron. Aluminum. Lead. Tin. Bismuth. Copper. Silver. Mercury. Platinum. Gold. Hydrogen. Antimony. Carbon. Phosphorus. Iodine. Chlorine. Nitrogen. Sulphur. Oxygen. −

The relative size of the plates associated in pairs does not alter the seat of action, or change the direction of the current. Suppose from this table we wished to find the action of a platinum-iron pair immersed in hydrochloric acid. Iron is + to platinum, and hydrogen + to chlorine. Chlorine, the negative element of the liquid, would accordingly be discharged at the electro-positive iron, and ferrous chloride ($FeCl_2$) would be formed. The electro-positive hydrogen would be disengaged at the electro-negative platinum. The interpolar current, consequently, proceeds from the platinum to the iron. If, however, no chemical affinity existed between iron and chlorine, no electricity would be generated, as chemical is essential to galvanic action. From such a list alone we cannot predict the result of any proposed combination. The metals themselves, as we have already seen, frequently change their relative positions, according to the action of the liquid in which they are put, so that the order given is by no means absolute. The arrangement of the metals in the foregoing table is according to their action in dilute acids. In different liquids or solutions metals frequently alter their mutual relations. Thus, in dilute sulphuric acid, silver is – towards lead; but in a solution of cyanide of potassium, + towards it. In a solution of common salt or potash, iron is +, copper –; in ammonia, iron is –, and copper +.

71. *The Negative protected by the Positive Plate—Local Action.*—The electro-negative plate remains in presence of the electro-positive totally unaffected, and more so than if it were placed by itself in the exciting liquid. Hydrochloric acid, for instance, readily attacks iron; but if a piece of zinc be put into the liquid, and be made to touch it, the iron will remain untouched until the zinc has been first dissolved. Wherever, therefore, iron is exposed to corrosive action, it may be protected from it by coupling it with zinc. This accounts, in some degree, for the durability of iron coated with zinc, or, as it is called, 'Galvanised Iron.' In the same way zinc protects copper from corrosive action. Davy found in his experiments to protect the copper sheathing of ships from the action of sea-water, that a plate of zinc protected 150 times its own surface of copper, when attached to the copper below water. A sheathing so protected suffered no corrosion, but lost for that

very reason its efficiency, as marine shell-fish and vegetables, finding it harmless, clung to it, and impeded the motion of the ship. On the other hand, zinc corrodes more readily in presence of a metal relatively negative to it, and hence, for example, the necessity for using zinc nails for zinc roofs instead of iron or copper nails. When pure zinc is put into dilute sulphuric acid, almost no change is visible, whilst ordinary commercial zinc is rapidly dissolved by it. This arises, in all probability, from different portions of the latter standing in different electric relations, arising from the heterogeneous structure introduced by extraneous substances. Galvanic pairs are thus established within the metal, and it dissolves in consequence. If the zinc plate of the pair were not amalgamated, *local action* would for this reason take place in it, which, as it contributed nothing to the circuit current, would produce a useless waste of the metal. When the plate is amalgamated, it becomes more + than before, and only dissolves when the circuit is closed.

72. *Quantity and Tension of the Electricity of a Current.*—The quantity of the electricity passing in a current, or the strength of the current (Fr. *Intensité*, Ger. *Stromstärke*), is estimated by the power of the current to deflect the magnetic needle, by the chemical decomposition it effects, or by the temperature to which it raises a wire of given thickness and material. The strength of the current must not be confounded with the strength of the cell or battery which gives rise to it. A battery of 100 cells is undoubtedly a stronger electric arrangement than one cell, yet, in certain circumstances, the one cell will give rise to as strong a current as the 100. The force of the battery, sometimes called the tension of the current, is the power which it has to transmit a current against resistance such as that offered by a bad, long, or thin conductor. Tension, strictly speaking, is not a property of the current, but of the battery which generates the current; it is a statical property (36), and is exhibited (59) by the insulated poles of the battery. A current of high tension is one which is maintained by a battery whose poles exhibit high tension. The tension of its poles is a measure of the electro-motive force of the electromotor (i. e., any arrangement such as a cell

or battery which generates a current, sometimes also rheomotor). By electro-motive force is understood the power to keep electricity in motion, or to maintain a current against resistance. The electro-motive force of any cell or battery may be measured before the circuit is closed, by connecting the zinc wire or – pole with the ground, and the insulated copper wire or + pole with a condensing electrometer, and observing the amount of statical tension—i. e., attraction or repulsion produced. The tension so measured gives the power of the arrangement to propagate electricity. When the circuit is closed, the electro-motive force is ascertained, as already mentioned, by introducing new resistance into the circuit, and observing the effect produced on the strength of the current. *The electro-motive force of the pair is proportional to the intensity of chemical affinity, or the force tending to chemical action, the current strength to the amount of this action or quantity of zinc dissolved in a given time, and the resistance is that which prevents the former from developing the latter.* Tension, when high, is also measured by the length of the spark.

73. *Greatest current that an electromotor can be made to give.*—The maximum current which any electromotor can give, is found by connecting the poles by a very good conductor, such as a short thick wire of copper, and observing the effect of this wire upon a needle. The greater the strength of the current is, the greater is the deflection of the needle. Chemical action and heating power cannot here be used as tests of strength, as, in order to produce these, considerable resistance must be placed in the circuit, which materially lessens the strength of the current. The maximum current which a galvanic pair can give is proportional to its surface. By doubling the size of the plates, we double the amount of current, provided, of course, the interpolar wire offers little or no resistance. The maximum current here spoken of has reference to the cell as we find it. It may be possible to improve its internal arrangement, but that is here considered fixed. The electromotive force is not affected by the size of the plates, but, as we shall afterwards find, by the number of pairs. Suppose, in illustration of what has been said, we had two pairs, one a

zinc-copper and the other a zinc-platinum, and that both gave the same maximum current. If the interpolar connection be then made by a long thin wire, the current which each gives will fall off, but that of the zinc-copper pair more than the other. This would be generally expressed by saying that both pairs were of the same quantity, but of different tension, the zinc-platinum pair being in that respect the stronger.

74. If an electric current be what we have supposed it to be, a series of molecules, rapidly discharging into each other, we must form the following ideas of its quantity and tension. If the series of cylinders shewn in fig. 35 were the medium of discharge between an electric machine and the ground, we should see sparks occurring at the small intervals between each at a certain rate. If the machine by any means were made to furnish twice as much electricity as at first, the spark would occur twice as quick. Or if, when the machine was giving off a double charge, we had two series of cylinders instead of one, the sparks would follow each other at the same rate as at first. Two series discharging at a certain rate do the same as one series discharging twice as quick. Similarly, any number of series would discharge the same amount of electricity as one, provided the rapidity of discharge of the latter were proportionally greater. A wire may be looked upon as several series of molecules placed side by side, and molecules, according to our theory, stand to each other much in the same relation as the cylinders just named. Accordingly, we must expect that a thin wire can produce as strong a current as a thick wire, provided its molecules discharge as much faster than those of the thick wire, as the section of the thick wire is greater than that of the thin wire. The strength of the current in this way depends on the number of molecules in the section of the wire, and the number of times they discharge in a given time. In statical electricity, we found that the quantity was got by multiplying the number of molecules or surface affected, by the tension or force lodged in each. In current electricity, we get the quantity much in the same way, by multiplying all the molecules in the section of the wire by the number of times they discharge in a given time.

Rapidity of discharge in the latter is equivalent to tension in the former. Whenever, in the former, the electric force concentrates, the tension rises; in the latter, the rapidity of discharge is increased. The electro-motive force arising from the intensity of chemical affinity is not increased by enlarging the plates, as the affinity is the same in a large as in a small plate. Large plates, however, by including a larger section of liquid, lessen the resistance within the cell, and thus far aid the development of chemical action.

Under the same electro-motive force, the rapidity of discharge is lessened when the connecting wire is long, but accelerated when it is thick. The resistance offered by a long series of molecules must be the sum of the resistances offered by each one; hence, the longer the series, the greater the resistance. Again, one series can convey a certain amount of electricity with a certain facility; another series will convey as much with the same; the two will convey twice as much electricity as easily as one series conveys the original amount. Or if one be made to convey as much as two, its molecules must discharge twice as fast; and having twice the work to do in the same time, will offer twice the resistance. Hence, the more series we have, or the thicker the wire, the better does it conduct.

75. *Comparison of the Electric Machine and the Galvanic Pair.*—The following experiment illustrates the relative characteristics of galvanic and frictional electricity. A Winter's electric machine, such as the two-foot plate described in article 45, gives readily, when in good order, a spark of twelve inches, and causes a visible disturbance of the leaves of an electrometer at a distance of twenty feet from it. If such a machine be made to send a current through a moderately sensible galvanometer in the way described in article 59, it will make the needle deflect one or two degrees. If a galvanic pair be connected with the same galvanometer, consisting of very fine iron and copper wires about an eightieth of an inch in diameter, immersed for about an inch into a few ounces of water containing one drop of sulphuric acid, the needle will deflect three or four times what it did before. The electricity of the current produced

in the diminutive pair is greater in quantity than that of the machine, but its tension is immeasurably smaller. Should a break be made in the circuit, the power of the terminal poles to attract or repel is almost infinitesimal, and discharge between them through the air cannot be effected even at a microscopic distance. Faraday has calculated that a wire of platinum and one of zinc, $\frac{1}{18}$th of an inch thick, immersed $\frac{5}{8}$ths of an inch in water containing sulphuric acid in the proportion of one drop to four ounces, will produce in three seconds as great a quantity of electricity as thirty turns of a fifty-inch plate-machine.

There seems to be something discordant in the results here obtained. The electro-motive force of the machine, as shewn by its tension, appears to be enormous, and yet, with almost no resistance, it barely produces a current. The force of the pair seems to be low, and yet the resulting current is very strong. This arises from the relative conditions of both being entirely different. In the galvanic pair, no matter how small it be, before an infinitely small circuit-resistance it would produce an infinitely strong current. Now, in the machine the quantity of electricity given off appears to be unaffected by the circuit-resistance. The conditions of both we might picture to ourselves in this way. Suppose we had an electric machine turned by a descending weight, and that somehow or other the resistance of the circuit, the only resistance in the case, was yoked to the plate, one turn of which always gave the same quantity of electricity to form the current; with a small circuit-resistance the weight would descend quickly, and the rapid rotation of the plate would give rise to a strong current; with a large resistance, the reverse would be the case. If the weight, which may be taken as the electro-motive force, were free to descend, the rapidity of rotation and amount of current would depend entirely on the resistance of the circuit. Here, if the weight were of moderate size, we would have the conditions similar to those of the pair. If the weight were enormous, but from some cause descended very slowly, it would turn the plate against any resistance, however great. Before a small resistance, however, it would soon exhaust itself, and appear almost to stop. Here we have conditions like those of the electric machine. High tension is the quality of electricity generated in the face of great resistance.

Galvanic Battery and Various Forms of Cells.

Galvanic Battery.

76. When a number of copper and zinc pairs, similar to the one already referred to, are put together, so that the copper plate of one cell is placed in conducting connection with the zinc plate of the next, in the manner shewn in fig. 67, they constitute a galvanic battery. The arrangement may be thus put: $\longrightarrow Z\underline{LC}\overline{}\underline{ZLC}\overline{}\underline{ZLC}\overline{}\underline{ZLC}\longrightarrow$, Z standing for zinc, L for liquid, and C for copper; the strokes below for the cell-connections, the strokes above for the wire-connections. The term battery is sometimes also applied to a number of cells acting as one combination, in whatever way they may be connected, and sometimes even to one cell. When the terminal copper and zinc plates (fig. 67) are connected, the current runs from each copper to each zinc plate without the liquids, and from each zinc to each copper plate within the liquids; and when the contact is broken, the zinc pole shews −, and the copper pole + E. The

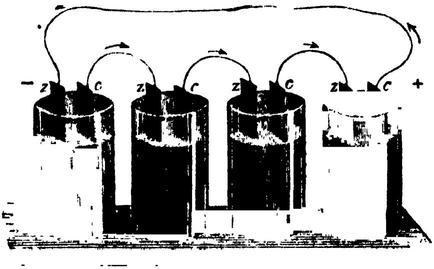


Fig. 67.

galvanic battery thus put up acts in all respects as a compound galvanic pair, and constitutes a compound galvanic or voltaic circuit. If the polar wires be connected with a tangent galvanometer, the deflection of the needle caused by the battery will be exactly the same as that effected by one of the cells, provided the wire be thick, and a good conductor —that is, the maximum current given out by a single cell and a battery is the same; but if the zinc end be connected with the ground, and the electric tension of the insulated copper pole be tested by a condenser and torsion balance, its tension is found to be as many times greater than the tension of the same pole of one cell examined in the same way as there are cells in the combination. Thus, if two cells be taken, the tension is doubled; if three, tripled; and so on. *The electro-motive force of a battery is therefore proportional to the number of cells*, supposing, of course, that they are arranged consecutively, as in the figure. Hence, when the interpolar connection offers great resistance—when it is, for instance, a very long and thin wire—the battery has power to maintain a current when the cell almost fails to do so. The fact that one cell gives the same maximum current as a battery of any number of cells, enables us easily to ascertain if all the cells of a battery are in order. Suppose, for instance, we wished to ascertain this for a battery of 100 cells, we take one cell, to all appearance in good order, and test its effect on the needle through a piece of thick copper wire; then we take the 100 cells, and test their combined effect in the same way. If both are the same, then all the cells are in order. The effect of the battery cannot possibly, in the circumstances, be greater than that of any one cell, but it may be less. If it is so, one or more of the cells in the chain are defective. If there is no local action, the quantity of zinc dissolved, and of hydrogen given off, in each cell or element of the compound circuit is exactly equal in amount, as is to be expected from the perfect homogeneity of every circuit.

The four cells in fig. 67, as stated, form a compound voltaic circuit. They may be made to form also a simple circuit. If all the zincs were connected with one wire, and all the coppers with another, and the circuit completed by one wire, then the four cells would act in every respect as one cell, whose plates had four times the surface. A battery, such as in the figure, would be said to have a tension arrangement; a battery, like the one named, a quantity arrangement.

That the electric tension should multiply with the number of cells, may be accounted for by the consideration, that instead of one polarising force, there are several, all acting in the same direction, each one exalting the polarity of the molecules produced by the other.

Different Forms of the Galvanic Battery.

77. *Volta's pile* is shewn in fig. 68. It consists of a number of circular plates, each made up of a plate of copper and a plate of zinc soldered together, built up, the copper plates facing one way and the zinc the other, each compound plate being separated by a circular piece of woollen cloth, moistened with a solution of common salt or dilute sulphuric acid. In consequence of the great number of pairs, the electric tension of the poles of Volta's pile is considerable. One furnished with from 60 to 100 plates can charge an electroscope without the condensing plates. It is from this battery that the term 'pile' is applied to the galvanic or voltaic battery. Volta used another form of battery, which he called a *crown of cups*. This consisted of a number of cells like those in fig. 62, arranged in a circle, so that the first and last were contiguous.

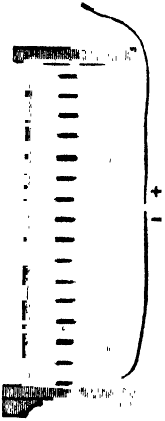


Fig. 68.

78. *Zamboni's Dry Pile* consists of several hundreds, and sometimes thousands, of discs of paper tinned on one side, and covered with binoxide of manganese on the other, put together consecutively, as in Volta's pile, and placed under pressure in an insulating glass tube closed with brass ends,

which serve as the poles. The electric tension of the poles of this arrangement is considerable, but the strength of the current which passes when the poles are joined is next to nothing. The most important application of the dry pile is in the construction of a very delicate electrometer, which is named after its inventor, *Bohnenberger's electrometer.* In this instrument the dry pile is insulated, and its ends are placed in conducting connection with insulated wires, which are bent round so as to face each other. The wires end in small faces, which thus constitute the poles of the pile. A gold leaf is hung between the poles, and turns to the one or the other according as it is charged. As we know the names of the poles, we know at once the name of the electricity with which the leaf is charged, as it must incline toward the opposite electricity.

79. *The Galvanic Trough,* introduced by Cruikshank, is a

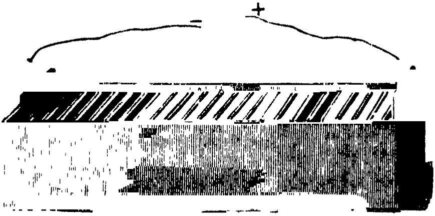


Fig. 69.

trough (fig. 69) into which rectangular plates of copper and zinc, like those of Volta's pile, are fixed, the cells included between each pair being filled with dilute sulphuric acid. The inner surface of the trough is coated with an insulating substance.

80. *Wollaston's Battery.*—Each couple of this battery (fig. 70) is made up of a plate of copper, doubled up so as to include a plate of zinc, from which it is kept apart by strips of wood. Both faces of the zinc are thus equally exposed to chemical and galvanic action, a device by which the quantity of electricity is increased. Fig. 71 shews a battery of five of these. The connecting strips of metal are

fixed to a wooden rod, by which they can be lifted or lowered together. When the battery is put in action, the whole is lowered, and the five couples are immersed in five troughs filled with dilute sulphuric acid (1 of the acid to 12 of water). When out of action, the whole is lifted and fixed

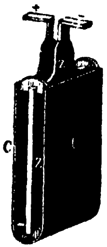


Fig. 70.

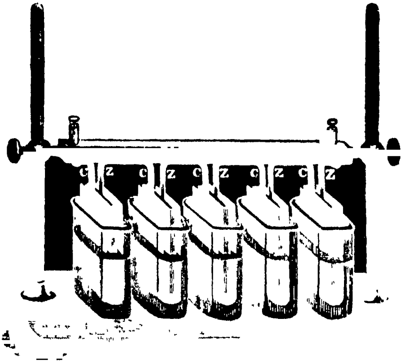


Fig. 71.

by binding screws to the two supporting pillars. When the number of pairs is small, as in the figure, it is of little consequence whether one large trough or five small ones be used.

81. *Smee's Battery.*—In Smee's couple, the position of the plates of Wollaston's couple is reversed. It consists of a silver plate, with a zinc plate on either side, kept separated from it by slips of wood, the two zinc plates being fastened by a coupling. There are thus two + plates to one −, instead of two − to one +, as in Wollaston's couple. The zinc plate has not thus to be so often renewed as in Wollaston's battery. The silver plate is platinised—that is, covered over with finely-divided platinum—and this is found to lessen the adhesion of the hydrogen bubbles to the plate, thereby greatly improving the constancy of the action. Smee's battery has the same arrangement as Wollaston's.

82. *Grove's Gas Battery.*—This battery is more intended for instruction than use. One of its cells is shewn in fig. 72. Into the two outer necks of a three-necked bottle, two glass tubes are fitted by means of corks through which they pass. Each of these tubes is open below, and a platinum wire enters them hermetically above, to which a long strip of platinum is soldered, extending nearly to the bottom of the tube. Little cups, containing mercury, stand at the upper ends of these s. The whole apparatus is filled with slightly acid water, and the poles of a galvanic battery are placed in the little cups. Water is thereby decomposed: oxygen forms in the one tube and hydrogen in the other. When the battery wires are removed, no change takes place till metallic connection is established between the cups, and the oxygen and hydrogen gradually disappear, attended by an electric current which passes from the oxygen to the hydrogen. When several of these are put together in a battery, the connection being always oxygen to hydrogen, they can decompose water. The most important fact illustrated by Grove's battery is, that the oxygen and hydrogen, liberated by galvanic agency, when left to themselves, produce a current the opposite to that which separated them. When the poles of the decomposing battery were in the mercury cups, hydrogen is given off at the −, and oxygen at the + pole; and as opposite electricities attract, it is manifest that the hydrogen in this action is +, and the oxygen −. When the two gases form, by means of the platinum plates, a galvanic pair by themselves, the current must proceed, as in all cases, from the + to the − within the liquid, and the reverse way between the poles; but this is the opposite of the direction of the original current.

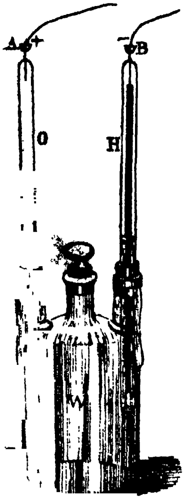


Fig. 72.

Galvanic Polarisation—Constant Batteries.—It is therefore manifest that where oxygen or hydrogen is set free at any point in a galvanic circuit, they will tend to send a counter-current. This tendency is called *galvanic polarisation.* This accounts for the fact, that no single galvanic pair can decompose water, as the force generated is no greater than the force of the counter-current that would be produced by the liberated gases. Even two cells produce an insignificant effect. Galvanic polarisation also accounts for the sudden falling off in strength in all galvanic couples where hydrogen is set free at the negative plate. The bubbles of the gas adhering to the plate, not only lessen the surface of contact between the plate and the liquid, but exert an electro-motive force contrary to that of the pair, and this goes on increasing until the action becomes greatly reduced. In all improved forms of the pair, it therefore becomes necessary to adopt some means of preventing the disengagement of hydrogen at the negative plate, and this is done in all *constant batteries* by employing two fluids instead of *one.* The best known constant batteries are those of *Daniell, Grove,* and *Bunsen.*

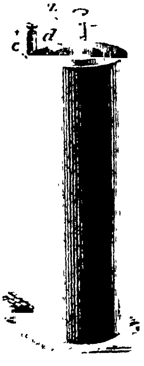


Fig. 73.

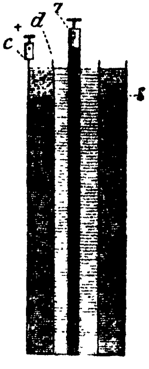


Fig. 74.

83. *Daniell's Battery.*—A cell of this battery is shewn in fig. 73, and a section of it in fig. 74. The containing vessel, *a,* is of

copper, which serves likewise as the negative element of the pair. Inside of this is another vessel, *d*, of porous unglazed earthenware containing a rod of zinc, *z*. The space between the copper and the porous cell is filled with a solution of the sulphate of copper, which is kept concentrated by crystals of the salt lying on a projecting shelf, *s*, and dilute sulphuric acid is placed with the zinc in the porous cell. When a tangent galvanometer is included in the circuit, the needle keeps steadily at the same point for hours. The rationale of its action is given as follows: The porous cell which keeps the fluids from mingling does not hinder the passage of the current; when the atoms of hydrogen that would ultimately be freed at the copper reach the porous cell, they displace the copper in the sulphate of copper, and copper instead of hydrogen is thrown on the copper plate. The chemical rationale of the action may be given by the following equations. Beginning with the copper (Cu) of the outer vessel, and ending with the zinc (Zn) of the rod, and taking $|^d$ for diaphragm or porous cell, we have the arrangement before discharge $Cu,\overline{CuSO_4}\ \ \overline{CuSO_4}\ |^d\overline{H_2,SO_4}\ \ H_2,\overline{SO_4}\ \ Zn$; and after it, $\overline{CuCu}$ $\overline{SO_4}|^dH_2\ \ S\overline{O}_4,H_2\ \ \overline{SO_4}Zn$. The discharge, therefore, effects a deposition of copper at the copper, and the formation of sulphuric acid at the porous cell and of sulphate of zinc at the zinc rod. Instead of hydrogen in its nascent state being deposited at the copper, we have copper in the same condition; but the galvanic polarisation caused by the latter is very much inferior to that resulting from the former, and hence the superior electro-motive force of Daniell's cell. The porous cell keeps the sulphate of zinc from reaching the copper, and thus obviates another source of diminished force in the one-fluid battery. The sulphate of zinc once formed, is itself subjected to the decomposing action of the pile, and zinc is deposited on the copper-plate, thus tending to give a zinc-zinc instead of a copper-zinc pair. The constancy of Daniell's battery is not unlimited, for the sulphate of zinc which results from the action, being a bad conductor of electricity, enfeebles the current. From its great specific gravity, however, it falls to the bottom of the cell, and may be removed by a siphon, and replaced by fresh liquid. The copper of the

Daniell's cell is frequently also placed inside the porous vessel, as the platinum in Grove's cell. A battery of Daniell's cells is put up in the usual way.

84. *Grove's Battery* consists of platinum-zinc couples. Fig. 75 shews an excellent arrangement of a cell of it. The outer cell of glass, *g*, is filled with dilute sulphuric acid (1 part of acid to 8 of water), in which a cylindrical plate of zinc, *z*, is immersed. Inside the zinc is a porous cell, *d*, containing concentrated nitric acid and the platinum plate, *p*, which is bent into the form of an S (fig. 76), to increase its surface. Grove's couple is very much superior in power to any of the preceding, though it is inferior in constancy to Daniell's. When the poles are joined, sulphate of zinc is formed in the outer cell, and the heavy brown gas, peroxide of nitrogen (N_2O_4), is given off by the nitric acid. As this gas is injurious to the health when breathed for any time, the porous cell is closed with a stopper of wood to prevent or lessen its escape, the connection between the exterior and the platinum plate being made by a strip of metal passing through the wood. The chemical action of Grove's couple may be shewn in the same way as Daniell's, taking anhydrous nitric acid (N_2O_5) to be the oxide of the peroxide of nitrogen (N_2O_4,O). Before

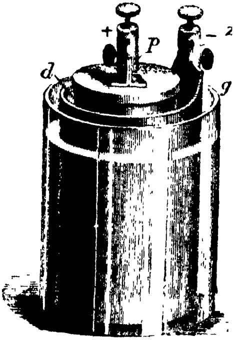


Fig. 75.

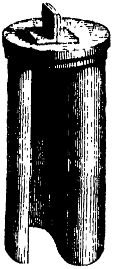


Fig. 76.

discharge, the molecules stand thus, beginning with the platinum: Pt, $\overline{N_2O_4,O}$ $\overline{N_2O_4,O}$ $|^d\overline{H_2,SO_4}$ $\overline{H_2,SO_4}$, Zn ; and after it, $\overline{Pt,N_2O_4}$ $\overline{O,N_2O_4}$ $\overline{O|^dH_2}$ $\overline{SO_4,H_2}$ $\overline{SO_4,Zn}$. The peroxide of nitrogen discharged at the platinum plate is absorbed by the nitric acid, in which it is soluble, so that the plate is left free. The resulting solution is highly conducting. The peroxide of nitrogen soon spontaneously separates from the nitric acid, giving rise to the dark-brown vapour already mentioned. The cells of a Grove's battery are connected with the platinum of the one to the zinc of the other.

85. *Bunsen's Battery.*—Bunsen's cell has the same chemical action as Grove's, the platinum being replaced by carbon. There are two forms of the cell—the one invented and employed by Professor Bunsen, and generally adopted in Germany ; and the modification introduced by Archerau, generally found in England and France. The Bunsen cell, properly so called, has a carbon cylinder immersed in nitric acid, and the porous cell containing the zinc and sulphuric acid placed within it. Fig. 77 represents a battery of four cells, shewing how the different cells are connected : *g* is the containing glass vessel ; *c*, the carbon cylinder ; *d*, the porous cell ; and *z*, the zinc. The other form of the Bunsen cell is shewn in fig. 78. In it the same arrangement is adopted as in

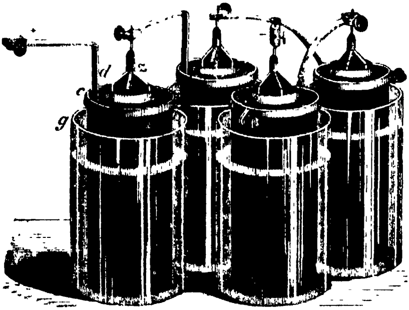


Fig. 77.

Grove's cell. Bunsen's battery, in point of cheapness, is preferable to Grove's, where the platinum forms an expensive item, but is inferior to it in point of compactness.

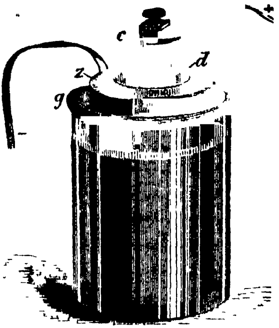


Fig. 78.

Bunsen Coke.—The carbons for Bunsen's battery are made by a process invented by Bunsen. The fine dust of coke and caking coal is put into a close iron mould of the shape required for the carbon, and exposed to the heat of a furnace. When taken out, the burned mass is porous and unfit for use, but by repeatedly soaking it in thick syrup, or gas tar, and reheating it, it at length acquires the necessary solidity and conducting power. The carbon that forms on the roof of gas-retorts is harder and better than the carbon thus made, but it is difficult to work, and the supply of it is limited.

Comparative Electro-motive Forces of different Cells.—Taking Muller's results, and expressing them in the electro-chemical units afterwards mentioned (96), the following numbers give the average electro-motive forces of the different cells: Bunsen's, 16·45; Grove's, 16·05; Daniell's, 9·67; Wollaston's, 4·13. This, of course, does not tell us the maximum current that can be got from each, for to determine that the size of the plates, their nearness, and the liquid resistance within the cell, must be also taken into account. The resistances within the cells for like surfaces for Daniell's and Grove's batteries have been variously estimated. Some give the resistance in Daniell's as six times, others two times greater than in Grove's. In Wollaston's cell the resistance is comparatively small from the absence of the porous cell, which offers very considerable resistance.

86. *Iron Battery.*—Instead of platinum, iron may be used with an equally good result in Grove's battery. Care must be taken that the nitric acid does not become dilute, for in

dilute nitric acid the iron is violently attacked. In the electro-chemical table, iron stands much inferior to platinum as an electro-negative metal. Its use in the iron battery depends on its becoming highly electro-negative in concentrated nitric acid, or assuming, as it is called, a passive condition. The *passivity of iron* can be produced in various ways. It becomes so when dipped in concentrated nitric acid, when heated in air or oxygen till it changes colour, or when it forms the + pole in the decomposition of water, where ozonised oxygen acts on it. Passive iron suffers no change in dilute nitric acid, which powerfully corrodes active or ordinary iron. The passivity of iron is attributed to the formation on its surface of a very thin layer of oxide, which is insoluble in nitric acid, and electro-negative compared with active iron. Passive iron can be made active by being rubbed with sand-paper, or heated in hydrogen gas. If in the iron battery filled with dilute acid there be any part not passive, that part forms a pair with the passive part, and rapidly dissolves. When the acid is concentrated, however, the surface is kept constantly passive.

Measurers of Current Strength.

87. The two powers of the galvanic current by which its strength is most conveniently measured are, its power to deflect the magnetic needle, and to effect chemical decomposition. To measure one or other of these is the object of a galvanometer or voltameter. A magnetic galvanometer shews the strength of the current by the amount of the deflection of the needle, and shews its direction by the way in which it deflects. The manner in which a needle should turn when influenced by a current is easily kept in mind by Ampere's rule: *Suppose the diminutive figure of a man to be placed in the circuit, so that the current shall enter by his feet and leave by his head; when he looks with his face to the needle, its north pole always turns to his left.* The deflecting wire is supposed always to lie in the magnetic meridian.

88. The *Astatic Galvanometer*, also called simply *Galvanometer* (Ger. *Multiplicator*), is used either simply as a galvanoscope, to discover the existence of a current, or as a measurer of the strengths of weak currents. When a needle is placed under a straight wire, through which a current passes, it deflects to a certain extent, and when the wire is bent, so as also to pass below the needle, it deflects still more. This is easily understood from the above rule. The supposed figure has to look down to the needle when in the upper wire, and to look up to it in the lower wire, so that his left hand is turned in different ways in the two positions. The current in the upper and the lower wire moves in opposite directions, thus changing in the same way as the figure; and the deflection caused by both wires is in the same direction. By thus doubling the wire, we double the deflecting force. If the wire, instead of making only one such circuit round the needle, were to make two, the force would be again doubled, and if several, the force (leaving out of account the weakening of the current caused by the additional length of the wire) would be increased in proportion. If the circuits of the wire be so multiplied as to form a coil, this force would be enormously increased. Two needles, as nearly the same as possible, placed parallel to each other, with their poles in opposite ways, as shewn in fig. 79, and suspended, so as to move freely, by a thread without twist, have little tendency to place themselves in the magnetic meridian, for the one would move in a contrary direction to the other. If they were exactly of the same power, they would remain indifferently in any position. They cannot, however, be so accurately paired as this, so that they always take up a fixed position, arising from the one being somewhat stronger than the other. This position is sometimes in the magnetic meridian, sometimes not, according as the needles are less or more perfectly matched, and their axes lie in the same vertical plane. Such a compound needle is called *astatic*, as it stands apart

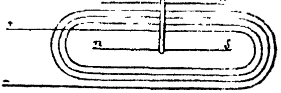


Fig. 79.

from the directing magnetic influence of the earth. If an astatic needle be placed in a coil, as in fig. 80, so that the lower needle be within the coil and the upper one above it, its deflections will be more considerable than a simple needle, for two reasons: in the first place, the power which keeps the needle in its fixed position is small, and the needle is consequently more easily influenced; in the second place, the force of the coil is exerted in the same direction on two needles instead of one, for the upper needle being much nearer the upper part of the coil than the lower, is deflected alone by it, and the deflection is in the same direction as that of the lower needle. An astatic needle so placed in a coil constitutes an astatic galvanometer. One of these instruments is shewn in fig. 80. Round an ivory bobbin, AB, a coil of fine copper wire, carefully insulated with silk, is wound, its ends being connected with the binding screws, *s*, *s′*. The astatic needle is placed in the bobbin, which is provided with a vertical slit to admit the lower needle, and a lateral slit to allow of its oscillations, and is suspended by a cocoon thread to a hook supported by a brass frame. The upper needle moves on a graduated circle; the compound needle hangs freely without touching the bobbin. The whole is included in a glass case, and rests on a stand, supported by three levelling screws. When used, the bobbin is turned round by the screw, Q, until the needle stands at the zero-point, and the wires through which the current is sent are fixed to the binding screws. The number of degrees that the needle

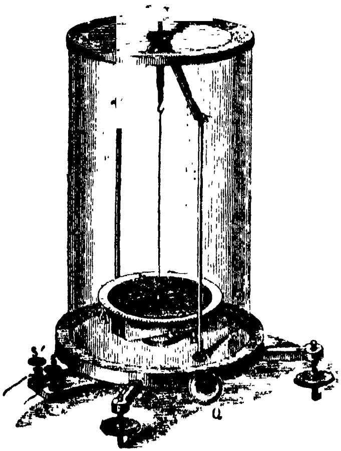


Fig 80.

deflects may then be read off. It is manifest that on deflection taking place, the different portions of the coil are differently situated with respect to the needle from what they are at zero; the deflecting force of the coil, therefore, differs with the position of the needle, so that the deflections caused by different currents are not in the proportion of the angles of deviation, or their functions; up to from 15° to 20°, it is found for most instruments that the strength of the current is proportional to the angle of deviation; beyond that, the relations of strength indicated by different angles must be ascertained experimentally, which can be done with the aid of a thermo-electric pile.

89. *Tangent Galvanometer.*—This instrument is shewn in fig. 81. It consists essentially of a thick strip of copper, bent into the form of a circle, from one to two feet in diameter, with a small magnetic needle, moving on a graduated circle, at its centre. When the needle is small compared with the ring, it may be assumed that the needle in any direction it lies holds the same relative position to the disturbing power of the ring. This being the case, *the strengths of currents circulating in the ring are proportionate to the tangents of the angles of deviation of the needle.* Fig. 82 shews how this is proved. Let MM be the magnetic meridian, or the plane of the ring, NS the needle, T the horizontal magnetic force of the earth acting parallel to the meridian, C the force of the current in the ring acting perpendicular to the meridian, and *d* the angle of deflection of the needle, ALM. T, represented by line ON, and C by BN, must be resolved each into two forces acting in a line with, and perpendicular to, the needle. T is resolved into ND and NE, and C into NG and AN. The perpendicular parts, GN and ND, must be

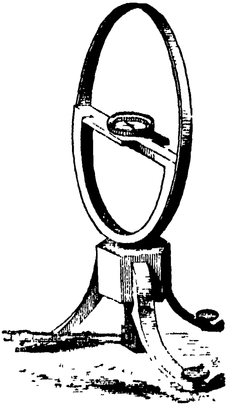


Fig. 81.

equal to each other if the needle is at rest, for they alone determine the turning of the needle. The other parts are neutralised by the opposite forces at the other end. Now,

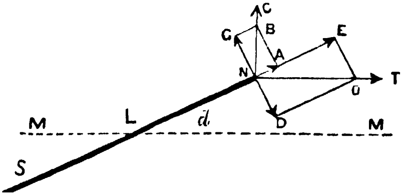


Fig. 82.

GN is C cos. *d*, and ND is T sin. *d;* and these being equal, it follows that C = T tan. *d*. As T may be taken as constant at the same point on the earth's surface, the force C varies with tan. *d*. Thus, if the deflection caused by one galvanic couple was 45°, and of another 60°, the relative strengths of the currents sent by each would be as the tangent of 45° to the tangent of 60°—viz., as 1 to 1·73. The needle can never be deflected 90°, for as the tangent of 90° is infinitely large, the strength of the deviating current must be infinitely great, a strength manifestly unattainable. The tangent galvanometer can consequently be used to measure the strongest currents. One great advantage attending its use is, that the current, in passing through the thick copper wire, experiences almost no resistance, and consequent diminution of strength, so that it can measure a current without affecting it. The strengths of the currents here got are simply relative. In article 132, we shall find that when the horizontal intensity of the earth's magnetism at the place of observation is known, the indications of the tangent galvanometer give the strengths in absolute electro-magnetic units. The determination of the horizontal intensity requires care and skill. By coupling the indications of the galvanometer with those of the voltameter, as shewn in the next paragraph, we have an easier way of reaching absolute results in electro-chemical units.

90. *Voltameter.*—This was invented by Faraday for testing the strength of a current. Fig. 83 shews how it may be

constructed. Two platinum plates, each about half a square inch in size, are placed in a bottle containing water acidulated with sulphuric acid ; the plates are soldered to wires which pass up through the cork of the bottle ; binding screws are attached to the upper ends of these wires ; a glass tube fixed into the cork serves to discharge the gas formed within. When the binding screws are connected with the poles of a battery, the water in the bottle begins to be decomposed, and hydrogen and oxygen rise to the surface. If, now, the outer end of the discharging tube be placed in a trough of mercury (mercury does not dissolve the gases), and a graduated tube (fig. 84), likewise filled with mercury, be placed over it, the combined gases rise into the tube, and *the quantity of gas given off in a given time measures the strength of the current.* The unit current may be taken as one which is capable of giving off one cubic centimetre of gas per minute. The voltameter chooses as a test the work which the current can actually perform, and establishes a uniform standard of comparison. The indications of the tangent galvanometer, as taken above, are comparable only with its own ; but the quantity of gas discharged by the voltameter, corrected for pressure and temperature, is something quite absolute. However, by comparing the indications of both instruments with each other when placed in the same circuit, an absolute standard may likewise be got for the tangent galvanometer. If, for instance, the current given by a battery should give 60 cubic

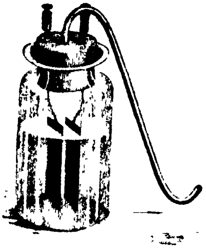


Fig. 83

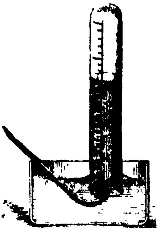


Fig. 84.

centimetres in a minute, as shewn by the voltameter, and produced at the same time a deflection of 45° in the galvanometer, the ratio of 60 to the tangent of 45°—viz., 60 to 1 = 60, is constant, for correct measurements of the strength of currents, however taken, must bear to each other a constant ratio. If the angle of deviation for another current be 30°, we have therefore only to multiply 60 by the tangent of 30°, to ascertain the amount of gas that would be liberated by a current of that strength in a minute. Thus, let x = quantity of gas with a current deflecting the needle 30°, then $\frac{x}{60} = \frac{\tan. 30^\circ}{\tan. 45^\circ} = \frac{\tan. 30}{1}$, therefore $x = 60 \tan. 30^\circ = 34{\cdot}6$ cubic centimetres of gas per minute. We are not to conclude that the electromotor that gives off this current would be able to effect so much decomposition in the voltameter; but we are told that if it could send through it a current of 30°, such would be the amount of explosive gas; or rather, in any voltameter through which a current of 30°, according to this particular galvanometer, is passing, the chemical decomposition equals 34·6 cubic centimetres per minute—a perfectly general measure. This found, we know the meaning of a deflection of 30° of the galvanometer in question in a perfectly comparable standard. The plates of the voltameter must be small, for when they are large, a small quantity of electricity is found to pass without decomposing the water. It is found, also, that a minute quantity of the oxygen forms peroxide of hydrogen (H_2O_2) with the water, and remains in solution, so that when very great accuracy is required the hydrogen alone ought to be measured.

Resistances to the Current—Ohm's Law.

Resistances to the Current.

91. It is found that the dimensions and material of substances included in the circuit exercise an important influence on the strength of the current. It is of the greatest importance to ascertain the relative amount of the resistance offered by conductors of various forms and materials. The *rheostat*, invented by Wheatstone, is generally employed for this purpose, and for this object is constructed so as to introduce into, or withdraw a considerable amount of highly resisting wire from, the circuit without stopping the current. It is shewn in fig. 85. Two cylinders, C′, C, about 6 inches in length, and 1½ inch in diameter, are placed parallel to each other, both being movable round their axes. One of them, C′, is of brass, the other, C, is of well-dried wood. The wooden cylinder has a spiral groove cut into it, making forty turns to the inch, in which is placed a fine metallic wire. One end of the wire is fixed to a brass ring, which is seen in the figure at the further end of the wooden cylinder; and its other end is attached to the nearer end (not seen in the figure) of the brass cylinder, C′. The brass ring just mentioned is connected with the binding screw, S, by a strong metal spring. The further end of the cylinder C′ has a similar connection with the binding screw, S′. The key, H, fits the projecting staple of either cylinder, and can consequently turn both. As the brass cylinder, C′, is turned in the same direction as the hands of a watch, it uncoils the wire from the wooden cylinder, C, making it thereby revolve in the same way. When the wooden cylinder is turned contrary to the hands of a watch, the reverse takes place. The number of revolutions is shewn by a scale placed between the two,

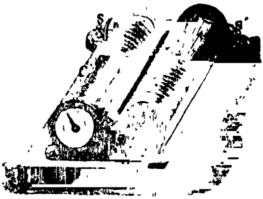


Fig. 85.

and the fraction of a revolution is shewn by a pointer moving on the graduated circle, P. When the binding screws, S and S′, are included within a circuit, say S with the +, and S′ with the – pole, the current passes along the wire, on the wooden cylinder, C, till it comes to the point where the wire crosses to the brass cylinder, C′; it then passes up the cylinder C′ to the spring and binding screw, S′. The resistance it encounters within the rheostat is met only in wire, for as soon as it reaches the large cylinder, C′, the resistance it encounters up to S′ may be considered as nothing. When the rheostat is to be used, the whole of the wire is wound on the wooden cylinder, C, the binding screws are put into the circuit of a constant cell or battery along with a galvanometer, astatic or tangent. If, now, the resistances of two wires are to be tested, the galvanometer is read before the first is put in the circuit. After it is introduced, in consequence of the increased resistance offered by it, the needle falls back, and then as much of the rheostat wire is unwound as will bring the needle back to its former place. The quantity of wire thus uncoiled in the rheostat is shewn by the scales, and is manifestly equal in resisting power to the introduced wire. The first is then removed, the rheostat readjusted, and the second wire included, and the same unwinding goes on as before. To fix our ideas, let the quantity of wire unwound in the first case be 40 inches, and in the second case 60 inches; 40 inches of the rheostat wire offer as much resistance to the current as the first wire, and 60 inches of it as much as the second. We have thus 40 to 60 as the ratio of the resistances of the two wires. The wire of the rheostat, from its limited length, can only be comparable with small resistances; and where great resistances are to be measured, large bobbins of insulated wire called *resistance coils*, whose resistances have been ascertained, are introduced into the circuit, or removed from it, as occasion requires, leaving to the rheostat to give, as it were, only the fractional readings.

92. The general principles of the construction of a rheostat being understood, it will be easily understood how the following results have been ascertained. It is proved, for instance, that the *resistances of wires of the same material, and of uniform*

thickness, are in the direct ratio of their lengths, and in the inverse ratio of the squares of their diameters. Thus a wire of a certain length offers twice the resistance of its half, thrice of its third, and so forth. Again, wires of the same metal, whose diameters stand in the ratio of 1, 2, 3, &c., offer resistances which stand to each other as 1, $\frac{1}{4}$, $\frac{1}{9}$, &c.; therefore, the longer the wire the greater the resistance, the thicker the wire the less the resistance. The same holds true of liquids, but not with the same exactness. For this reason, the larger the plates of a galvanic pair, and the nearer they are placed to each other, the less will be the resistance offered to the current by the intervening liquid. The following table, constructed by Ed. Becquerel, gives the *specific resistances* of some of the more common substances, or the resistance which a wire of them, so to speak, of the same dimensions offers at the temperature 54° F.: Copper, 1; silver, ·9; gold, 1·4; zinc, 3·7; tin, 6·6; iron, 7·5; lead, 11; platinum, 11·3; mercury (at 57°), 50·7. For liquids, the resistances are enormous as compared with the metals. With copper at 32° F. as 1, the following liquids stand thus: Saturated solution of the sulphate of copper at 48° F., 16,885,520; ditto of chloride of sodium at 56° F., 2,903,538; sulphate of zinc, 15,861,267; sulphuric acid, diluted to $\frac{1}{11}$, at 68° F., 1,032,020; nitric acid at 55° F., 976,000; distilled water at 59° F., 6,754,208,000.

If such be the resistance of distilled water, which is a conductor for frictional electricity, how inconceivably great in comparison must be the resistance of those substances which are non-conductors to it.

93. *The conducting power* of a substance is inversely proportional to its resisting power, the more it resists the worse it conducts. The list just given therefore gives inversely the conducting power of the substances mentioned, so that taking the conducting power of silver as 100, we get that of each of the other substances by dividing 90 by the resistance of that metal. Instead of giving Becquerel's conducting table, we may give Mathiessen's more recent determinations (1858). In the following table the first column gives the conducting power of the metals for electricity according to Mathiessen, and the second column their conducting power for heat

according to Wiedemann—silver, the standard, being 100:

CONDUCTING POWER OF METALS.

	Electricity.	Heat.		Electricity.	Heat.
Silver, . .	100	100	Platinum, . .	10·5	8·4
Copper, .	77·4	73·6	Lead, . .	7·7	8·5
Gold, . .	55·2	53·2	German Silver, .	7·7	6·3
Sodium, .	37·4	...	Antimony, .	4·3	...
Aluminum, .	33·8	...	Mercury, . .	1·6	...
Zinc, . .	27·4	28·1	Bismuth, .	1·2	1·8
Potassium, .	20·8	...	Graphite, . .	·069	...
Iron, . .	14·4	11·9	Gas Coke, .	·038	...
Tin, . .	11·4	15	Bunsen Coke, .	·025	...

The different determinations of the conductivity of metals agree generally as to order, but differ as to precise numbers. This arises from the difficulty of getting metals in the same state of purity or hardness. The slightest admixture of a foreign metal alters the conducting power decidedly; ½ per cent. of iron in copper wire increases the resistance more than 25 per cent., and a trace of arsenic 66 per cent. Mathiessen has found that the relative conducting powers of the various simple metals remain the same at temperatures between 1° and 100° C. Metals at 100° C., compared with themselves at 0° C., lose about 30 per cent. of conducting power. In the case of iron only, it is 38 per cent. Annealing improves conducting power. German silver is well adapted to resistance coils, because of its specific resistance, and because its conducting power is affected to a slight extent (4 per cent.) between 1° and 100° C. Non-metallic substances generally improve in conductivity as they rise in temperature.

94. *Unit of Resistance.*—Various units of resistance have been suggested, such as a certain length of copper or other wire of a certain thickness, but the difficulty in all such cases is, that specimens of wire are seldom found of the same purity or structure, so that the results in one case are not comparable with those in another. The British Association of 1864, following a suggestion of Weber, that an electric resistance might be expressed as an absolute velocity, or as a length divided by time (130), independently of the nature of the

substance offering it, have agreed upon an ideal absolute standard, which, according to the perfection of the means of observation, they will be able materially to express. This is called the *B. A. Unit of resistance* 1864, *or an Ohmad* (from Ohm). The following table will give an idea of its physical meaning, according to present means of realising it. It is expressed in B. A. units :

B. A. Unit (1864.)—A velocity of 10,000,000 metres per second, ...	1·0000
Siemens's Unit.—A column of pure mercury, 1 metre long, and 1 square millimetre in section at 0° C.,	0·9563
Varley's Unit.—One mile of ordinary copper wire (perhaps more correctly of a certain copper wire), $\frac{1}{16}$th of an inch in diameter (No. 16 wire), at 60° F.,	25·61
Digney's Unit. One kilometre of iron wire, 4 millimetres in diameter, ...	9·266
The following units are used by various observers. Their value in B. A. Units is determined by Dr Mathiessen (*Phil. Mag.* 1865) :	
A wire at 0° C., of 1 metre length, and 1 millimetre diameter, of—	
Silver (pure, annealed), ...	0·01937
Copper (pure, annealed), ...	0·02057
German Silver (pressed), ...	0·2695

According to Mathiessen's suggestion, the B. A. unit is embodied in a platinum-silver alloy, containing 66·6 per cent. of silver, whose conducting power is 6·7, and loses only 3·1 per cent. of conducting power from 1° to 100° C. It has, moreover, this advantage, that it does not, as German silver sometimes does, alter its conducting power after long use. The repeated heatings caused by the passage of the current tend to anneal the wire, and lessen its resisting power, but this does not affect the alloy in question. Copies of the B. A. unit in a wire of this alloy are issued by the Kew Observatory.

Ohm's Law.

95. *Ohm's Law.*—This law is singularly in accordance with experimental results. It assumes that the electro-motive force for a particular galvanic pair is constant, and that the strength of the current it produces is the quotient which results from dividing it by the resistance of the circuit. This resistance

arises from two sources; the first being the resistance within the cell offered by the exciting liquid, and the second the interpolar resistance. If e represent the electro-motive force; l, the resistance within the cell; w, the interpolar resistance; and S, the strength of the current, or the quantity of electricity actually transmitted, the statement of the law for one couple stands thus: $S = \frac{e}{l + w}$. The application of the law in a few particular cases will best illustrate its meaning. If we increase the number of cells to n, we increase the electromotive force n times, and at the same time we increase the liquid resistance n times, for the current has n times as much of it to travel, then $S = \frac{ne}{nl + w}$. If w be small compared with nl—that is, if the external connection be made by a short thick wire—it may be neglected, and so $S = \frac{ne}{nl} = \frac{e}{l}$. This shews that one cell gives in these circumstances as powerful a current as a large battery, and that the increased electro-motive force is expended in pushing the current through the liquid in each cell. But if nl be small with respect to w—as in the interpolar circuit of an electric telegraph battery—nl may be neglected, and $S = \frac{ne}{w}$. Here we learn that the energy of the current increases directly as the number of cells. We may learn from the same that the introduction of the coil of long thin wire of a galvanometer into such a circuit, introducing but a comparatively small increase of resistance, causes a very slight diminution of the current strength. If, again, we increase the size of the plates of a galvanic pair n times, the section of the liquid is proportionately increased, so that whilst the electro-motive force remains the same, the cell resistance diminishes n times; therefore $S = \frac{e}{\frac{l}{n} + w}$, or $S = \frac{ne}{l + nw}$. If the exterior resistance is small, nw may be neglected, and $S = \frac{ne}{l}$, and the strength is thus shewn to increase n times.

96. *Application of Ohm's Law.*—To apply Ohm's law practically, we must have some means of measuring the strength of the current S, and the resistances l and w. These ascertained, we have data sufficient to determine e. The instruments which serve for this object, already described, are the tangent galvanometer and rheostat. If we are contented with relative results, the simple indications of the galvanometer, and the resistance offered by any length (fixed on as a unit) of the wire we use for the rheostat, will serve our purpose. But if we wish absolute results, we must, in the first place, include our galvanometer and a voltameter in a circuit of several cells, and compare the indication of the needle with the cubic centimetres of gas given off by the voltameter per minute (90). In the instrument that we use let the voltameter give off 30 cubic centimetres, while the needle indicates a deflection of 26½° (tangent = ·5 or ½ nearly). By simple proportion, we find that if it gives off 30 cubic centimetres at 26½°, it will give off at 45° (tangent = 1) 60 cubic centimetres. To express the indications of our tangent galvanometer on an absolute standard of measure of gas, we have therefore to multiply 60 by the tangent of the angle it may indicate. In the second place, we must ascertain what length of the wire we use corresponds to a well-known unit of resistance, say the B. A. unit. Thus furnished with an absolute measure of current and resistance, we may take as *a unit of electromotive force that which can generate one cubic centimetre of gas per minute in a circuit of a B. A. unit of resistance.* Having connected the poles of the cell to be examined with the galvanometer by short thick wires (so that the interpolar resistance may be left out of account), we find the angle to be 51⅓° (tangent = 1·25). The strength of maximum current is 60 × tan. 51¼ = 80 cubic centimetres of gas. Include now one unit of the rheostat wire into the circuit, the angle falls to 12¼° (tangent = ·22 = $\frac{2}{9}$). The strength of the current is now $60 \times \tan. 12\frac{1}{4}° = 13\frac{1}{3}$. In the first case, the interpolar resistance, w, is nothing, therefore $80 = \frac{e}{l}$; in the second, $13\frac{1}{3} = \frac{e}{l+1}$. From these two equations, it follows

that *l*, the liquid resistance within the cell, is ·2, or $\frac{1}{5}$th of a B. A. unit, and that *e*, the electro-motive force, is 16—that is, in a circuit whose resistance is one unit, the electro-motive force would be able to disengage 16 cubic centimetres of gas per minute. The same might be found for a battery of several cells in the same way, only more resistance must be included in the circuit to reach accurate results.

Suppose now that we have nine cells similar to the one just discussed. Let us, for the sake of simplicity, suppose that they are exactly equal, and that results come out exactly in accordance with Ohm's law. Practically, this never takes place, but the discrepancies can be easily accounted for, as they originate in the apparatus, or faults of observation, and not in the law. Practical results, however, are so near the law as to leave no doubt of its truth. Let us ascertain how these nine cells would act when differently put up. One cell, when $w = 0$, gives a current 60; when $w = 1$, a current $13\frac{1}{3}$. Instead of one unit of resistance, interpose say 15, so as to make up the total resistance of the circuit to 15·2, or 76 times the liquid resistance of one cell. In this case, $S = \frac{16}{15 \cdot 2} = 1 \cdot 05$. To find that such is the case, we refer to the galvanometer, where we find the needle at 1°. Now, $60 \times \tan. 1° = 1 \cdot 05$ nearly. Let us now put up the nine cells in succession, as in fig. 86. Here the electro-motive force of the whole battery is nine times that of one cell, or 144, and the resistance of the whole is also increased nine-fold, or $9 \times \cdot 2 = 1 \cdot 8$, as the current has in the compound circuit to traverse nine times the amount of liquid it has in one. Thus, $S = \frac{144}{1 \cdot 8 + 15} = 8 \cdot 6$, more than eight, and nearly nine times the current that one cell can transmit. The galvanometer will confirm this result as in the previous cases.

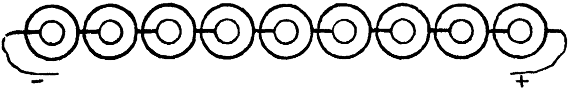


Fig. 86.

Instead of the tension-arrangement just investigated, let us have a quantity-arrangement of the cells as in fig. 87. The

Fig 87.

electro-motive force is not increased, but the resistance is nine times diminished, seeing that the whole acts as one cell of nine times the surface. Here $S = \frac{16}{\frac{\cdot 2}{9} + 15} = 1\cdot 06$, very little more than that given by one cell. Again, put up the nine cells as shewn in fig. 88, where we have three batteries of three cells each, each joining to form one current, the whole acting as one battery, with the plates three times enlarged. $S = \frac{48}{\frac{\cdot 2}{3} + 15} = 3\cdot 1$, or about three times the current of one cell. Before a large resistance, the surface is best employed by being cut up into small cells, arranged successively, than by having a few large cells. Before a small resistance the reverse holds. *The maximum effect is got when the total liquid resistance within the battery is equal to the external or interpolar resistance.* This, of course, is only practicable when the interpolar resistance is less than the resistance of all the cells put together.

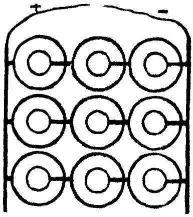


Fig. 88.

When continuous work has to be done by a battery, the size of the plates or cells must not be too small, as small cells containing little zinc and acid soon become exhausted. Large cells do not before great resistance give a stronger current than small cells, but they continue in action for a much longer time. The quantity, therefore, on the whole, that a large cell gives is greater than that of a small cell, although the quantity made to flow by it at a time may not exceed that of the small cell.

97. When cells differing both in electro-motive force and liquid resistance are put up successively, we have to add all the electro-motive forces for the electro-motive force, and all the resistances for the resistance of the battery. Thus, if we had six cells with the electro-motive forces 9, 8, 7, 10, 6, 12, and the resistances $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, $\frac{1}{5}$, $\frac{1}{6}$, $\frac{5}{12}$, respectively, the total electro-motive force would be 52, and the total resistance 2, and we should have the formula $S = \frac{52}{2 + w}$. If the last two happened to be reversed and acted in the contrary way, the formula would be $S = \frac{34 - 18}{2 + w}$, the total liquid resistance being the same as before.

98. *Derived Currents.*—Let *np* (fig. 89) be a rheomotor whose circuit is completed by the wire *pacbn*, at *a* and *b* attach another wire, so that from *a* to *b* another course, *adb*, is made from *a* to *b*, then the following terms are applied. The current which originally passed through *pacbn* is called the *primitive current;* that which passes through the circuit, including the additional branch, the *principal current;* that part of the principal current which traverses the course *acb* from *a* to *b*, the *partial current;* the other part of it passing by *adb*, the additional course, the *derived current;* *a* and *b* are the points of derivation, the wire *adb* the *derived wire*, and the course *acb* is the *interval of derivation.* The principal current must be stronger than the primitive current, because the additional wire from *a* to *b* lessens the resistance of the whole circuit. It is found that the current passing in the two wires is exactly equal in amount to that passing in the undivided wires, *pa* and *bn*, and that the parts of the principal current

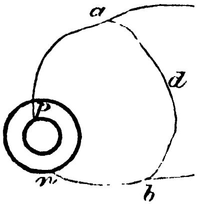


Fig. 89.

passing in *acb* and *adb* are inversely proportionate to the resistance each offers. Thus, let the principal current be 24, the resistance of the interval of derivation 5, and of the derived wire 3, the partial current will be 9, and the derived current 15. The same would hold if there were more than one derived wire.

The Physiological, Heating, Luminous, and Electrolytic Effects of the Galvanic Current.

These are developed by the current in its path.

99. *The physiological effects*, as shewn by the convulsions of Galvani's frog preparation, were the first observed manifestation of the current. Fig. 90 shews how these convulsions are obtained. The legs of a recently killed frog are skinned, and the crural nerve laid bare. A zinc wire, BA, holds up the nerve at B, and a copper wire, EA, is made to touch the legs at E and D. Each time that the zinc and copper wire is made to join at A, the limbs are convulsed, and the contraction of the muscle throws the legs out to the position *ff*. Frog-limbs, as prepared by Galvani, when included in a circuit, form a galvanoscope of excessive sensibility, which rivals the finest galvanometer in delicacy of indication. There is one peculiarity in their action which deserves to be noted. The limbs contract only when the circuit is closed and opened, and remain undisturbed so long as the current passes steadily through them. The more frequently, therefore, the current is stopped and renewed, the greater is the physiological effect. The same is experienced when a current is passed through the human body. When the terminal wires of a battery are lifted one by each hand, except it consist of a very large number of

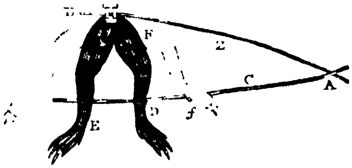


Fig. 90

cells, almost the only sensation felt is a slight shock on completing and breaking the circuit. Du Bois Reymond, the great authority on animal electricity, states that the nerves of motion are affected only by changes in the electric tension of the current, whereas the nerves of sensation, so far as they are affected, are affected not only by these, but also by the steady continuance of the current, and that the excitation of the nerves dependent on the changes of tension increases with their frequency and suddenness. Frictional electricity in this way owes its superior physiological power to the instantaneous nature of its discharge. It is only currents of great tension which can be felt by the living subject. The poles of a battery of 50 Bunsen cells, capable of giving a brilliant electric light, for instance, may be handled without much inconvenience. This may be attributed partly to the non-conducting nature of the skin. If the current enter the body by a cut or wound, the sensation is affected even when the current is weak. The physiological effect is also much heightened by moistening the hands with salt and water, or by holding metal handles instead of wires, so as to improve the conducting connection. Another cause of this insensibility may be attributed to the fact that the current is not restricted, as it is in part of the frog preparation, to the nerve, but passes through all the conductors of the system. The nerves of the palate and of sight can be affected by a very feeble current; those of hearing by a battery of some 30 cells. If two strips of silver and zinc be placed the one above, the other below the tongue, and be made to touch, a peculiar taste is experienced; when the strips are placed between the gums and the cheeks, and joined, a flash of light accompanies each junction. Again, when the poles of a battery of 30 cells are inserted into the ears, a continuous noise is heard.

100. *Heating Effects.*—When a current passes through thin wires, an intense heat is produced, sufficient, when strong enough, to bring them to a white heat and to fuse them. Experiments on the heating effects of the current are made by an apparatus such as that sketched in fig. 91. B is a bottle filled with alcohol (which is non-conducting), and closed with a cork. The thick wires, *n*, *p*, passing through the cork, are

connected with the poles of a battery, and within the bottle they are joined with a thin spiral wire, *www*; *t* is a delicate thermometer. When the circuit is closed, the heat developed in the wire is communicated to the alcohol, the temperature of which is shewn by the thermometer. It is found that if the wire *www* be kept the same, or of the same resistance, the heat developed is in proportion to the square of the strength of the current. Thus, if a current of strength, say 30 units of gas, as shewn by the tangent galvanometer, raise the contents of the bottle 1° in a minute, a current of twice the strength, 60 units, would raise it 4° in a minute. Again, if by means of a rheostat, by which resistance can be introduced or withdrawn from the circuit, the strength of the current be kept at the same point, and wires of different resistance be put into the bottle, it is found that the heat developed is proportional to the resistance of the wire. Thus, suppose that with a wire offering a resistance 1, the contents of the bottle are raised 1° per minute, with a wire resisting 2, and the same current strength, the increase would be 2° per minute. Hence *the heat developed in any conducting wire by an electric current is proportional to the squares of the strengths of the current, and to the resistance offered by the wire.*

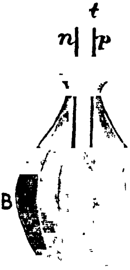


Fig. 91.

Knowing the strength of the current, the resistance of the wire, the weight of alcohol, the increase of temperature in a given time, we may determine the heating powers of the current. If the thin wire offer one B. A. unit of resistance, and the strength of the current be 20 electro-chemical units, the heat given off will be sufficient to raise 482 grammes of alcohol 1° C. in a minute. The same heat would raise only 337 grammes of water 1° C., for the specific heat of alcohol is $\frac{7}{10}$ths of that of water. A current of unit strength will, according to the above rule, produce only $\frac{1}{400}$th part of this, or ·84 gramme raised 1° C. According to the law stated above, the heating effect depends on the strength of the current and the resistance. Hence a current of a certain strength will heat up any length of a thin wire to the same amount if the current be kept at the same point. This gives us the means of estimating roughly the strengths of currents. Currents which can raise a wire of a certain material and thickness to a certain heat, say a red or a white heat, must be of the same strength, the length of the wire heated being no criterion of strength, though it may be of electro-motive force.

A very pretty illustration of the fact that the heat developed is proportional to the resistance encountered, is offered by a chain, the alternate links of which are made of silver and platinum. When a current of sufficient strength passes through the chain, the silver links remain black while the platinum links become red-hot.

The application of the heating powers of the current to igniting gunpowder in mining, &c., is detailed in the Practical Applications of Current Electricity.

101. *Galvanic Spark.*—When the wires connected with a powerful galvanic battery are brought together, no current passes except they are made to touch, or nearly so. On the separation, a brilliant spark takes place, due, as we shall afterwards find, to induction (119). According to Sir William Thomson, a battery of 5000 Daniell's cells could not originate a spark, if its poles were placed $\frac{1}{20}$th of an inch apart. In Gassiot's water battery of 3520 well-insulated cells, a spark passed when the poles were brought to ·02 of an inch, and continued to do so uninterruptedly for weeks and months together. When the galvanic spark is examined with a microscope, it is found that the light only appears at the — pole. The electric light, the most splendid exhibition of the lighting and heating power of the current, will be described under Practical Applications.

Electrolysis.

102. *Electrolysis* (from *electro*, electric, and *lysis*, a disengaging) is the term used by Faraday to designate that branch of the science of galvanism which treats of the laws and conditions of electro-chemical decomposition. As this decomposition is generally attended by electro-chemical combination, it is sometimes difficult to distinguish electrolysis from the more general subject of *Electro chemistry*, which embraces all chemical changes resulting in or from the galvanic current. Electrolysis is generally understood to treat of the changes effected in a substance subjected to, but not giving rise to the current.

Faraday's Nomenclature.—A substance capable of decomposition by the current is called an *electrolyte* (something unbound by electricity). The poles—viz., the wires, plates, or the like—by which the current enters and leaves the electrolyte are called *electrodes* (electric ways, from *hodos*, a way), the + pole being called the *anode* (*ana*, up, and *hodos*), and the − pole the *cathode* (*cata*, down, and *hodos*). The constituents into which the electrolyte is decomposed are called *ions* (from *ion*, going); the electro-positive substances, or those going to the cathode, are called *cations*; and the electro-negative substances which go to the anode are called *anions*. To *electrolyse* signifies to decompose by electric agency.

General Character of Electrolytes.—No substance is decomposed by the current so long as it is in a solid or gaseous state, and it must first be brought to a *liquid state*, either by solution or fusion, before the current acts on it. There are some unimportant exceptions to this. The passage of electricity through compound gases in a state of great rarity, as in the so-called vacuum tubes, frequently separates them up into their constituents. The electric spark in air effects the combination of oxygen with nitrogen; nitric acid being produced. Electrolytes must be *chemical combinations*, as these only can be decomposed. Metallic alloys, when fused, though they conduct the current, are not decomposed by it.

103. ***Electrolytes are resolved under the action of the current into anions and cations, which appear at their respective electrodes in the proportion of their atomic weights or multiples of their atomic weights.*** The action of the current on one or two substances will best illustrate the meaning of this law.

Electrolytes.	Composition.	+ Cations.	— Anions.	Relative Proportions.
Hydrochloric Acid, .	HCl	H	Cl	1 to 35·5
Chloride of Sodium,	$NaCl$	Na	Cl	23 to 35·5
Sulphuric Acid, . .	H_2,SO_4	H_2	SO_4	2 to 96
Sulphate of Sodium,	Na_2,SO_4	Na_2	SO_4	46 to 96
Sulphate of Ammonium,	$(H_4N)_2,SO_4$	$(H_4N)_2$	SO_4	36 to 96
Water, . . .	H_2O	H_2	O	2 to 16

Thus common salt ($NaCl$) is composed of a simple cation Na, whose atomic weight is 23, and of a simple anion, Cl, whose atomic weight is 35·5. Sulphate of ammonium is composed of two atoms of ammonium $(H_4N)_2$ as a complex cation, and one atom of sulphion (SO_4) as a complex anion. The atomic weight of ammonium (H_4N) is 18, and of sulphion (SO_4) 96. It will be thus seen that chemical formulæ give the electrical as well as chemical composition of electrolytes. In acids, hydrogen forms the cation, and the acid radical, the other constituent, the anion. In the salts of an acid, the metal that takes the place of hydrogen in the acid is the cation of the salt, and the other constituent, the salt radical, is, as in the acid, the anion.

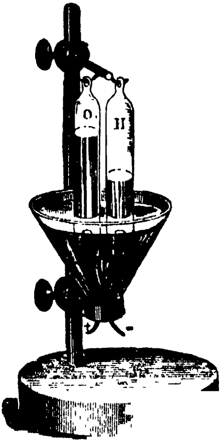


Fig. 92.

The decomposition of water by platinum plates is always taken as the best visible illustration of electrolytic action. Fig. 92 represents a very convenient apparatus for the purpose. A glass basin is made so as to admit a cork below, through which two wires pass having slips of platinum plate soldered to them above. Two glass tubes, open below, are hung over the plates, to hooks projecting from an upright support. The bowl is filled with acidulated water; and the tubes, after being filled with the same, are inverted, and hung with their lower ends enclosing the plates. When the wires projecting downwards from the cork are connected with the poles of the battery, hydrogen rises from the −, and oxygen from the + electrode, to fill each its separate tube. As the decomposition proceeds, twice as much hydrogen is liberated as oxygen. When the tubes are filled, they may be removed and examined.

Hydrogen is here the type of the metals, or other electro-positive substances, disengaged at the − pole, and oxygen of the acid and salt radicals, or other electro-negative substances, set free at the + pole. Moreover, the proportions of the volumes of the two gases being that of their chemical combining volumes, reminds us that, when a body is decomposed, its components are always separated in the proportions in which they were united, viz., those of their atomic weights. If the tubes of this apparatus were graduated, it would serve for a voltameter. Platinum plates are here employed because platinum does not enter into combination with either of the gases, so that both are disengaged. The oxygen got by this process smells strongly of ozone. This shews that the gas, when electrically set free, possesses more than usual chemical activity, a characteristic common to the products of electric decomposition. They are set free in what is called their *nascent state*, in which they form combinations with other substances with more than usual readiness.

Secondary Action.—When the sulphate of copper is decomposed by two copper electrodes, copper is deposited at the − pole, and SO_4 enters into combination with the copper of the + pole, and neither oxygen nor hydrogen is disengaged. When platinum electrodes are used, copper is deposited at the one and oxygen is disengaged at the other. The reason is this, SO_4 does not enter into combination with platinum, and when set free acts on the water in which the salt is dissolved, forming oxygen and sulphuric acid. Thus, $SO_4 + H_2O =$

$H_2,SO_4 + O$. The liberation of the oxygen thus arises from a purely chemical action, subsequent to electrolytic action. This is called *Secondary Action*, which denotes, as here, the action of the liberated ions upon the constituents of the solvent or substances present in it. Secondary action is well shewn by the apparatus that Daniell employed for the electrolysis of salts. This consisted of a voltameter in which the gases were collected separately, having a porous diaphragm dividing it into two compartments. When such an apparatus is filled with a solution, say of sulphate of sodium, and subjected to the current, oxygen and hydrogen are set free, as they would be in a voltameter like the one described in fig. 92. At the same time soda is formed in the cathode compartment and sulphuric acid in the other. The current thus seems to do double work; it appears at the same time to decompose water and the sulphate of sodium. This double action must be attributed to secondary action. Sulphate of sodium, Na_2,SO_4, is decomposed into the cations Na_2 and the anion SO_4. Na_2, in the presence of water, becomes soda, Na_2O, and liberates hydrogen, thus $Na_2 + H_2O = Na_2O + H_2$; and SO_4, acting also on the water, becomes, as already shewn, sulphuric acid and oxygen. Thus the separation of the constituents of the salt is due to electric action, and the liberation of oxygen and hydrogen to a secondary chemical action. *The decomposition of water*, in an ordinary voltameter, *is very probably due to secondary, not primary action.* If it be charged with pure water, little or no decomposition is effected, even when the battery consists of 30 or 40 cells. On the addition of a few drops of oil of vitriol, the gases are disengaged in abundance. It is thus, probably, the sulphuric acid that is decomposed in the first instance, and the water in the second. Electrolytic action splits up H_2SO_4 into H_2 at the − pole, and SO_4 at the + pole; the former is freed, the latter acting on the water becomes sulphuric acid again, and liberates oxygen in the way just shewn. No sulphuric acid is lost in the operation, but it is constantly unformed and re-formed. It is considered by many authorities that water never yields directly to the current—that it is not, in fact, an electrolyte. With the exception of the case of fused chlorides, and when one of the poles is eaten away, and the other receives a metallic deposit, electrolysis is almost always accompanied by secondary action, it being frequently a matter of difficulty to unravel the primary from the secondary action in the results.

When there are several electrolytes in one decomposing cell, all are more or less acted upon when the current is strong, but when it is weak, the action is confined to the best conductor, or to the one yielding most readily to the current. Water, the usual solvent, is never decomposed directly when it holds an electrolytic salt in solution, the action being expended exclusively on the salt.

104. *When there are several electrolytes each in distinct cells in the same circuit.* If, instead of one voltameter included in the circuit, we have several, we find that, whatever amount of gas is liberated in one of these, the same amount is liberated in all, and that independent of the size of the plates and amount of acid in each. We learn, therefore, that the chemical power of the current is the same at every point of the circuit where it is manifested. If, instead of two or three voltameters in the circuit, we had one or two decomposing cells of the following description. A test tube, having a platinum wire, on which the glass has been fused, passing through the bottom, is partially filled with protochloride of tin, which is kept fused by the heat of a spirit-lamp. The platinum wire at the bottom of the tube forms one electrode, and one descending from the top forms the other, dipping below the fused chloride. If, then, this cell be included in the circuit along with the voltameter, and a similar cell containing fused chloride of lead, so that the current enters the tubes by the upper electrodes, and leaves by the lower, the water, protochloride of tin, and chloride of lead are decomposed simultaneously by the current passing through each. In the voltameter, hydrogen and oxygen are disengaged; in the tubes metallic tin is deposited at the lower electrode of the one, and lead at the other; whilst chlorine is liberated at the upper electrodes of both. If, now, the quantity of hydrogen, tin, and lead thus set free be weighed, it will be found that their weights are in the proportion of their chemical equivalents—viz., as 1 to 59 to 103. From

such experiments as these, Faraday concluded that *when the current passes through a series of binary electrolytes, consisting of one equivalent of each of the elementary bodies, the quantities of the separated elements of the electrolytes are in the same proportion as their chemical equivalents.* It is not only in cells exterior to the battery that this law holds, but in the cells of the battery itself. If the battery which effected the above decomposition consisted of six cells, for each equivalent of hydrogen, tin, and lead separated without the battery, one equivalent of zinc (= 32) in each cell would have been dissolved, and an equivalent of hydrogen disengaged at each of the copper plates, if the cells were one-fluid. Hence, also, if in any circumstances one cell of say Bunsen's battery gives a current as strong as two cells of a one-fluid arrangement, the Bunsen cell would consume but half the zinc consumed in the other. Hence the economy of cells of great electro-motive force.

Faraday's law holds also for binary compounds whose elements do not stand in the relation of an equivalent of the one to an equivalent of the other, but with this modification, that the weights of the *electro-negative elements* alone, separated in the action, are in the ratio of their equivalents. Thus, if the same current pass through two decomposing cells, one containing a solution of the subchloride of copper ($CuCl$), consisting of an equivalent of copper and half an equivalent of chlorine, and the other of the chloride of copper ($CuCl_2$), consisting of an equivalent of each, the same quantity of chlorine will be disengaged in both, but twice as much copper is deposited in the first as in the second. Had there been a compound of copper with the formula ($CuCl_3$) containing an equivalent and a half of chlorine capable of decomposition, we should expect in the same way that for one equivalent of chlorine disengaged there would be $\frac{2}{3}$ds of an equivalent of copper. Becquerel from such instances expresses Faraday's law somewhat to this effect: *When the same current passes through a series of electrolytes, the weights of the separated anions are to each other as their chemical equivalents.* The anions here mentioned may be either simple or complex, although the law at first had reference only to elementary substances. Thus, if one cell contained tribasic phosphate of sodium (Na_3PO_4) in solution, and the other chloride of sodium ($NaCl$), one atom of PO_4 being equivalent to three of Cl, for every atom of PO_4 set free in the one cell, three atoms of Cl would be disengaged in the other. The atomic weight of PO_4 is 95, of 3Cl 3 times 35·5—viz., 106·5. The cations and anions are disengaged in each cell according to the law (103).

The amount of decomposition effected by the current is in proportion to the current strength. This law has been already assumed in the discussion of the voltameter (90). The accuracy of this law is somewhat compromised by the fact that liquids possess, to a certain extent, the power of conducting, physically, electricity without electrolytic action, so that all that passes in this way is chemically lost. Fortunately, the error thus introduced is very small, and can be therefore practically disregarded.

Electro-metallurgy.—The application of electrolysis to the arts will be found in the last section.

Chronology of Galvanism.

105. The science of galvanism dates from the close of the 18th century. In the year 1780, Galvani, in making investigations on the nervous irritability of cold-blooded animals, discovered by accident that the limbs of a recently killed frog, when hung by the crural nerve on a metal support near an electric machine, contracted convulsively at the recurrence of each spark. This he properly accounted for by the back-stroke (48). Six years afterwards (1786), in experimenting on atmospheric electricity with frog limbs as delicate electroscopes, he obtained, also accidentally, the same convulsions by bringing the copper hook on which the nerve hung, and the limb itself, simultaneously in contact with an iron railing. The similarity of the result led him to attribute it to the same cause—viz., electricity either existing in the limb itself or produced in the conducting arc of metal. On consider-

ation, he adopted the former hypothesis, and looked upon the limb as a self-charging Leyden jar, with the nerve as the brass knob and wire; the interior of the muscle as the inner coating, its exterior the outer coating, and the metal arc as the discharging tongs. He first published his researches in 1791. Volta, 1792, discarded the account given by Galvani of his experiment; and from the fact that the convulsions in question took place with more energy when there were two metals in the conducting arc instead of one, attributed the source of electricity to the heterogeneity of the metals employed. He maintained that at the surface of contact of two different metals an electric force arising from their heterogeneity is generated, which throws them into different tensions. This doctrine forms the fundamental principle of the *contact theory* of galvanism. In reply to Volta, Galvani proved incontestably that the contraction in the limbs of the frog took place when only one metal was employed, and even when the conductor was not of metal at all. Subsequent discovery has proved Galvani to be partly right in attributing the cause of these convulsions to animal electricity, and Volta also to be partly right in attributing them to electricity generated by the two metals, for both causes may be at work in producing the result. Fabroni, a professor at Florence, was the first (1792) to suggest *chemical action* as one of the causes at work in Galvani's experiment. Volta did not accept of Galvani's vindication, but supported his theory by several apparently conclusive experiments. In 1799, he constructed, as the crowning evidence of the truth of his reasoning, his pile, and with it properly begins the history of galvanism. To Galvani is thus due the merit of discovering a new manifestation of electricity; to Volta is due the merit of displaying in it a source of power of incalculable importance, and which, but for his genius, might have remained among the barren curiosities of science. Hence it becomes a question of some difficulty to decide to which of the two the science owes its origin —whether it is to be called Galvanism or Voltaism. Priority of discovery has led men generally to decide in favour of Galvani, although Volta has almost equal claim to have his name attached to the science.

The first account of Volta's pile reached England in a letter to Sir Joseph Banks by the inventor (1800). A few weeks afterwards, Carlisle and Nicholson decomposed water with it, and afterwards several salts. They were the first to use platinum electrodes. Davy, in the same year, traced the electricity of the pile to chemical action. Wollaston (1801) reiterated the same theory, and went the length of attributing even frictional electricity to chemical action. He proved likewise the identity of the two electricities, and shewed that, by diminishing the electrodes to mere points, the electricity of the machine could produce the same chemical effects as that of the pile. In 1802, Cruikshank improved the construction of the pile, by disposing the plates horizontally in a trough instead of vertically in column. The main features of electro-chemical decomposition were discussed by Davy in his famous Bakerian Lecture of 1806. In 1807, the same philosopher obtained for the first time, by galvanic agency, the metals potassium, sodium, barium, strontium, calcium, and magnesium. Deluc (1809) first made dry piles of gold and silver paper, and these were altered and improved by Zamboni (1812). In 1813, Davy discovered the electric light and voltaic arc by means of the colossal battery then placed at his disposal at the Royal Institution. Œrsted (1820) first observed the action of the current on the magnetic needle; and a few months afterwards, Ampere discovered the law of this action, and originated an electric theory of magnets, which has proved wonderfully fertile in practical results. In the same year, Schweigger invented the galvanometer. In 1825, Becquerel, with the aid of his differential galvanometer, investigated the conductibility of metals. Kemp, in 1826, first used amalgamated zinc for the galvanic battery. In 1827, Ohm gave a mathematical theory of the pile, rigidly deduced from Volta's fundamental principle, and in perfect keeping with experiment. Faraday discovered (1833—1834) the definite nature of electro-chemical decomposition, and proved that electro-chemical and chemical equivalents were identical. In 1836, Daniell constructed his constant battery. Spenser in England, and Jacobi in Russia, made simultaneously (1837) the discovery of electro-metallurgy. Grove (1839) constructed his nitric acid battery. Faraday (1840) proved, apparently beyond dispute, the truth of the chemical theory. Joule (1840) discovered the law regarding the production of heat by the current. In 1840, Cooper suggested the use of carbon, and Hawkins that of iron, for platinum in Grove's battery. Smee's battery dates also from this year. In 1843, Wheatstone, by means of his rheostat and resistance coils, investigated the resistances offered by various conducting substances to the current. In the same year Bunsen introduced his carbon battery.

The rivalry which has all along existed between the advocates of the chemical and contact theories has been highly conducive to the advancement of the science, each party calling in the aid of invention and discovery to support the truth of their statements. Among the more distinguished contact-theorists may be mentioned Volta, Ritter, Pfaff, Biot, Deluc, Ohm, and Fechner; and among the chemical-theorists, Fabroni, Davy, Wollaston, Parrot, De La Rive, and Faraday. Davy latterly maintained a theory of distribution and equilibrium of electricity midway between the two, which numbered among its supporters Jæger, Berzelius, Ermann, and Prechtl.

ELECTRODYNAMICS—ELECTRO-MAGNETISM—CURRENT AND MAGNETO-ELECTRIC INDUCTION.

These all treat of the action of the current out from its path. The first two are closely allied, there being some difficulty in drawing the line of demarcation between them. With some writers, electro-magnetism includes electrodynamics.

Electrodynamics.

Electrodynamics treats of the *mutual attractions and repulsions of currents on currents, and currents on magnets.*

106. *Currents on Currents.*—The fundamental principle of current attraction is, *that parallel currents in the same direction attract, those in opposite directions repel.* In fig. 93, the action in the first case is shewn, A denoting attraction. Hence currents, however placed, endeavour to put themselves parallel, so as to run the same way. From this may be deduced the second principle of current-attraction, that *cross or angular currents attract when they both run from or to the point of crossing, but repel when they run the one to, the other from, the crossing-point.* The first case is shewn in fig. 94. From this second principle follows a third regarding currents that are perpendicular to each other, but do not cross each other. Let EF (fig. 95) be a current at right angles to the current BD, or to a plane through it, and let it come up near to C, the crossing-point. The currents BD and FE

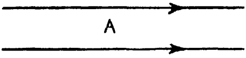


Fig. 93.

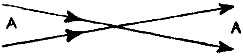


Fig. 94.

are of indefinite length, or which is the same thing, they turn away from their present direction, so far off that the change of direction does not affect their action on each other as they stand. Then, by the second law, EF and CD repel, because they run in different directions as regards the crossing-point. Let this repulsion be shewn by the line *ac*. For the opposite reason BC and EF attract, and let *ad* represent the attraction, then by the parallelogram of forces, the combined effect will be equivalent to the single force *ab*, which is parallel to BD. Hence, *when one current is perpendicular to another current, or to a plane passing through it, the former current is moved backwards and parallel to the latter when it runs towards it, and forwards when it runs from it.*

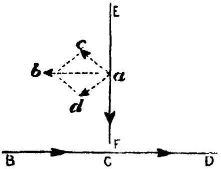


Fig. 95.

107. These three laws give us the means of unravelling the various actions of one current on another. The first two may be experimentally illustrated by an apparatus such as that shewn in fig. 96. The rectangle *cdef* is movable round the pins *a* and *b*, resting on two mercury cups, which act as binding screws to complete contact. The arrangement is such that while the rectangle *cdef* is movable about its axis, a current can continue steadily to flow in it. Further description is unnecessary, as the diagram explains itself. It can be easily understood, that a wire conveying a current may be placed, with regard to the different parts of the rectangle, so as to illustrate the two first laws. Thus, if a

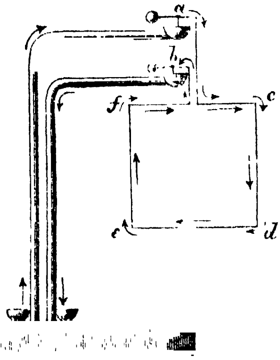


Fig. 96

wire conveying a downward current be brought near to *cd*, so as to be parallel to it, attraction will take place ; if it be presented to *fe*, repulsion will ensue. A current-wire held horizontally with respect to *cd* can be placed so as to make the currents both tend to the crossing-point between them, or the opposite, so as to illustrate the second law. It may be objected, that in this apparatus we cannot examine the effect on one part of the current without also taking in the other parts of the rectangle, but these last may be made to stand comparatively so far off as not to affect the main result.

108. The third law may be shewn by an apparatus such as that in fig. 97. A is a small circular trench containing mercury, surrounded by a coil of insulated copper wire, *ww*. The metal rod, BB, is surmounted by a small cup of mercury. A light copper wire, *bacd*, is poised on a fine point in the cup *n*, and its lower ends, *d*, *b*, dip into the mercury of the trench. The circuit is so arranged that the current enters at *w*, traverses the coil, passes to BB (connection not shewn), which it ascends, at the cup entering the copper wire it splits into two branches, descends along *ab* and *cd* to the mercury, and leaves finally for the battery at *o*. As soon as the circuit is closed, the wire *bacd* enters into constant rotation. In the coil the current moves contrary to the hands of a watch ; the wire, according to the third law, moves backward upon it in the direction of the hands of a watch. In the figure the horizontal parts of the current *na* and *nc* are so far above the current as to affect the motion slightly, if at all. But if the upright branches *ab* and *cd* were short, so as to leave the motion almost entirely to *na* and *nc*, the wire would still rotate as before, for the currents *na* and *nc* are also

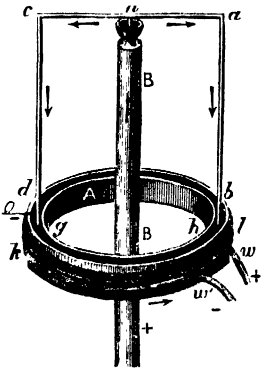


Fig. 97.

perpendicular to the current of the coil, though in a different but parallel plane, and both run towards it, thus standing in the same relation as before. If the current be reversed, the motion of the wire is also reversed.

109. A curious consequence is considered to follow from the second law—namely, that since two parts of a straight line may be regarded as standing at a very obtuse angle to each other with reference to a point in it, any point in the straight line may be looked upon as the crossing-point of its two parts. As at the point taken we find the one part of the current approaching the other leaving it, the two parts of the current repel each other. Hence *the various parts of a current, in a straight line, repel each other.* Faraday, in illustration of this, bent a wire in the form of a horseshoe, and made each end of it dip into a separate vessel containing mercury. The wire was partly supported by the mercury, and partly by the beam of a delicate balance. When the poles of a battery are put into the vessels the wire loses weight, from the repulsion of the mercury conveying the same current as itself. This experiment, it must be confessed, is not quite decisive, as the repulsion may arise from the peculiar action of a fluid on a solid part of the circuit. The mutual action of currents on each other was first elucidated by Ampere in 1825.

110. *Currents on Magnets.*—The mutual attractions and repulsions of currents and magnets will be best understood by following Faraday's first experiment on the subject (1821), which we shall here quote. Let NS (fig. 98) be a magnet, moving round its centre C, and let the round black dots represent the section of a wire, conveying a current perpendicularly to the needle. The upright wire is so long that the wire, when it changes direction, has no effect on the needle. Suppose we look down on the needle, and that the current is upwards. Then in the positions, A, A′, a, a', the needle is attracted by the current; in R, R′, r, r', it is repelled. At N and S, if placed there, the wire produces no effect. Faraday

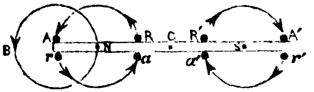


Fig 98.

concluded, from this singular action, that if the poles were fixed the wire would rotate round the north pole in the direction RAra, and round the south pole in the direction R′A′$r'a'$; and that if the poles were free to move about the fixed current, the north pole would rotate in the direction shewn in the circle NB. Experiment verified this conclusion. Before proceeding to detail the manner in which he effected these rotations, we may note the directions in which these rotations take place. *If an observer be placed at the north pole of a magnet, parallel to a movable current, so that the current is seen by him to flow upwards, the rotation of the current round the pole would appear to him to be from right to left;* and *to an observer placed in a fixed current, with the current entering at his feet, the north pole of the magnet would appear to him to move round him from right to left.* This last is only another way of stating Ampere's rule. The directions for the south pole are the reverse. The apparatus by which Faraday actually effected these rotations was as follows. M and N (fig. 99) are two vessels containing mercury, with wires entering them below, so as to effect their communication with the poles of a battery; b is a small powerful magnet, tied by a thread to the wire at the bottom; F is a magnet, fixed to the bottom of the vessel N; d is a copper wire, hung by a metal hook. When the current passes, as in the figure, the movable magnet b rotates round the fixed wire e, and the movable wire d revolves round the fixed magnet F, in the direction according to the rules just given. If the upper ends of F and b be south poles, the rotation of b will be in the same direction as the hands of a watch, and of d in the opposite way.

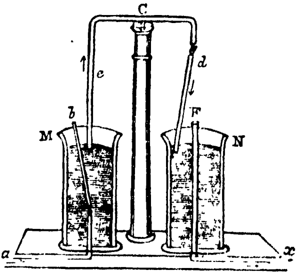


Fig. 99.

111. *Law of Electro-magnetic Rotations.*—Biot and Savart

have stated the law of electro-magnetic rotations thus. *The force with which each element (small part) of a current acts on a magnetic pole, stands at right angles to the plane passing through the element and the pole, and is always inversely proportional to the square of the distance.* If such be the action of a current on a pole, the pole must act in the same way on a current. This law gives the mutual action of a current and one pole, but it may be so placed that both poles affect it. The direction, in this case, of the joint action of both poles is that of the line of magnetic force at the current (2). Hence in any magnetic field, *each element of a current, when free to move, is urged in a direction at right angles to the lines of magnetic force.* Ampère's figure *in* the current (entering at his feet), looking to the north pole, will be urged towards the right.

112. *Action of the Earth on Currents.*—The lines of magnetic force on the earth's surface are parallel to the dipping-needle, and currents have a tendency to move at right angles to them. In order to ascertain the action on any portion of a current by the lines of magnetic force, we have simply to project it on a plane at right angles to the lines of force or to the dipping-needle. If the line to be projected lies at right angles to the dipping-needle, then its projection on the plane will be of the same length as itself, and the action of the earth-magnetism will be to urge it perpendicular to the lines of force and to itself, and in a direction determined by the position of the poles of the earth to it. If the line be parallel to the lines of force, then its projection will be a point or the section of the wire; and as there can be no perpendicular to such, it is manifest that the line in this position has no tendency to displacement under magnetic influence. The force of terrestrial magnetism on it is null. A line between these two positions will appear shortened when projected on the plane, and the direction in which it is urged will be indicated by the perpendicular to the projected line. The shorter the line becomes in projection, the less it is exposed to the displacing influence of terrestrial magnetism.

Let us apply the principles just stated to the case of the revolving wire, fig. 97, when the coil is placed out of the circuit. Let us suppose the lines of magnetic force resolved into two sets, horizontal and vertical lines, as in art. 17. Let us confine our attention to one half, *nab*, of the wire. The vertical lines of force have no influence on the vertical part, *ba*, because it is parallel with them, and its projection on a horizontal plane would be a point. To *na*, whatever position it occupies in its circle of rotation, the vertical lines will be at right angles, and exert their full force on it. *na* rotates in presence of the north pole of the earth, which, according to our way of speaking, is a south pole; it will therefore rotate contrary to the hands of a watch. Let us now see how the horizontal lines act. *ab* stands always perpendicular to them, whatever be its position. It will accordingly be urged to the right as far as it can go, which is in a position in which it lies east of BB. Here it will be in stable equilibrium, and it will resist being moved westwards one way or other. In this position *na* would be urged upwards by the horizontal lines, which, from its mode of suspension, cannot take place. The effect of the horizontal lines on *na* is to move it downwards in its west, and upwards in its east position, but not to interfere with its motion in a horizontal plane. In the position in which *nab* stands east of BB, it becomes a question of strength whether *na* shall carry it on, or *ab* keep it standing. If it is to rotate, *ab* must be made shorter than *na*. If both halves be now taken into account, *cd* and *ab* will have a tendency to place themselves both east of BB; they will therefore counteract each other, and leave the motion of the wire to *na* and *nc*, which will keep it in constant motion.

On a closed circuit, such as that of fig. 96, the effect of terrestrial magnetism will be to place the plane of it at right angles to the magnetic meridian. The horizontal parts will have no effect. The whole will be left to the vertical currents, which, passing the one up the other down, will place themselves, *cd* to the east, *ef* to the west. It is from the conflicting action of its parts that a closed circuit, as a whole, cannot continue to rotate in a magnetic field.

Electro-magnetism.

Electro-magnetism includes all phenomena where magnetism is produced by an electric current. In the description of galvanometers some of the principles of electro-magnetism have been already discussed.

113. *Ampere's Theory of Magnetism.*—This theory forms the link between magnetism and current electricity, and gives a simple explanation of the electric action and constitution of magnets. Ampere considers that every particle of a magnet has currents circulating about it in the same direction. A section of a magnet, according to this theory, is shewn in fig. 100. All the separate currents in the various particles may, however, be considered to be equivalent to one strong current circulating round the whole (fig. 101). We are to look upon a magnet, then, as a system, so to speak, of rings or rectangles, placed side by side, so as to form a cylinder or prism, in each of which a current in the same direction is circulating. Before magnetisation, the currents run in different directions, so that their effect as a system is lost, and the effect of induction is to bring them to run in the same direction. The perfection of magnetisation is to render the various currents parallel to each other. Soft iron, in consequence of its offering no resistance to such a disposition, becomes more powerfully magnetic under induction than steel, where such resistance exists.

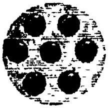


Fig. 100.

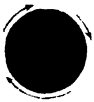


Fig. 101.

Experiment very strongly confirms the truth of this theory. Helices of copper wire, in which a current is made to circulate, manifest all the properties of a magnet. Such are shewn, in skeleton, in figs. 102 and 103. Each convolution of the spiral may be taken as a substitute for one of the rings above spoken of. In helix, fig. 102, the current, after entering, goes from right to left (contrary to the hands of a watch), and it is hence called left-handed; in fig. 103 it goes with the hands of a watch, and is right-handed. The extremities of both helices act on the magnetic needle like the poles of a magnet while the current passes. The poles are shewn by the letters N and S, and this can be easily deduced from Ampere's rule; for, suppose the little figure of a man to be placed in any part of the helix, fig. 102, so that while he looks towards the axis of the helix the current enters by his feet, and leaves by his head, the north pole will be at his left hand, as shewn in the figure. In the left-handed helix (fig. 103), the poles are reversed according to the same rule. Or, if we suppose the figure to lie in the axis of the magnet with his feet to the south, and his head to the north pole, the current of the helix, or the molecular currents of the magnet, appear to him to run from right to left, or contrary to the hands of a watch. In fact, a single ring, as well as a system of rings, conveying a current has magnetic sides, that being north on which the current appears to go contrary to the hands of a watch, and that south on which it moves with the hands of a watch. If either of these helices be hung so as to be capable of horizontal motion, which by a simple construction can easily be done, as soon as the current is established the north and south poles place themselves exactly as those of the magnetic needle would do; or if they were hung so as to be able to move vertically in the magnetic meridian, they would take up the position of the dipping-needle. When the helices are so hung, the wires, going in a spiral to the end, must be brought back again in a straight line to the middle. When they are so constructed, they receive the name of solenoids. It is found by experiment

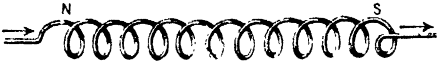


Fig. 102

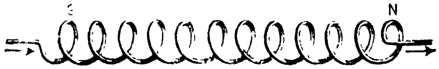


Fig. 103.

that a sinuous current destroys the effect of a straight current of the same length as its axis. The longitudinal effect of the solenoid—that is, its action in the line of the axis—is null, as the effect of the straight current going out from the middle is neutralised by that of the sinuous current returning, and *vice versâ*. The magnetic properties of the solenoid are thus due solely to its being a system of parallel currents. Weber has shewn that coils of wire act on each other not only in kind but in amount as magnets do.

Ampere's theory explains very satisfactorily why like poles repel, and unlike attract. Figs. 104 and 105 shew this. Two north poles near each other (fig. 104) have opposite currents on their adjoining side, and repel each other in consequence (106). A north and a south have similar currents, and attract.

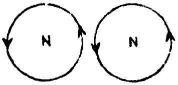


Fig. 104.

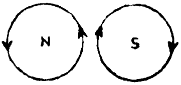


Fig. 105.

If the north pole of a magnet were placed parallel to BB in fig. 97, the coil being left out of the circuit, the rotation would take place as shewn in the figure; if the south pole be put in the same place, the motion of the wire will be reversed. According to Ampere's theory, it may be also easily explained why a closed circuit rests in equilibrium at right angles to the magnetic meridian, and why the axis of a magnet which lies in the axis of a series of such closed circuits places itself in the meridian. The earth, being a magnet, has currents circulating about it, which must be from east to west, the north pole of the earth being, in our way of speaking, a south pole. A magnet, then, will not come to rest till the currents moving below it place themselves parallel to and in the direction of the earth's currents. This is shewn in fig. 106, where a section of a magnet is represented in its position of rest with reference to the

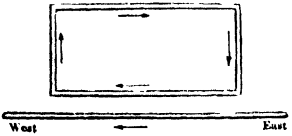


Fig. 106.

earth-current. The upper current being further away from the earth-current, is less affected by it, and it is the lower current that determines the position. A magnetic needle, therefore, turns towards the north to allow the currents moving below it to place themselves parallel to the earth's current.

114. *Electro-magnets.*—Perhaps the strongest proof of the truth of Ampere's theory is the fact that when a current wire is coiled round a piece of soft iron, the iron becomes for the time powerfully magnetic. The general form of an electro-magnet is shewn in fig. 107. It consists of a round bar of soft iron bent into the horseshoe form, with an insulated wire coiled round its extremities. When a current passes through the coil, the soft iron bar becomes instantly magnetic, and attracts the armature with a sharp click. When the current is stopped, this power disappears as suddenly as it came. Electro-magnets far outrival permanent magnets in strength. Small electro-magnets have been made by Joule which support 3500 times their own weight, a feat immeasurably superior to anything performed by steel magnets. When the current is of moderate strength, and the iron core more than a third of an inch in diameter, *the magnetism induced is in proportion to the strength of the current, and of the number of turns in the coil.* It is of no importance whether the coils be placed all over the magnet or accumulated at the ends. When the bar is thinner than one-third of an inch, a maximum is soon reached beyond which additional turns of the wire give no additional magnetism; and even when the core is thick, the advantage gained by increasing the number of coils may be lost by the long circuit reducing the strength of the current. The maximum that can be reached is, in different magnets, proportional to the area of section, or to the square of the diameter of the core. It is found also, when the mass of the armature is equal to

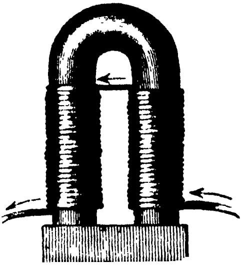


Fig 107.

that of the core, that *the weight which the magnet sustains is in proportion to the squares of the strengths of the currents.* The length of the electro-magnet has no other advantage than that of insulating the poles, the one from the other. When the core consists of a bundle of insulated wires, it is capable of greater magnetisation than when it is solid. The rust that sooner or later forms on iron wires is sufficient insulation. The electro-magnet, from the ease with which it is made to assume or lay aside its magnetism, or to reverse its poles, is of the utmost value in electrical and mechanical contrivances. That the electro-magnet may quickly acquire, and as quickly lose its magnetism on closing and breaking the circuit, it is necessary that the iron be perfectly pure or soft, and well annealed. It is also necessary that the armature be kept just short of touching, for when it is in contact, a residuum of the induced magnetism lingers in it and in the core after the current stops. Under current induction the various molecular currents, according to Ampere's theory, place themselves parallel to each other, and act powerfully in concert. The direction of the current and the nature of the coil being known, the poles are easily determined by Ampere's rule.

115. *Magnetic Tick.*—When an iron rod is made to rest on a sounding-board, such as the body of a fiddle, and placed in the centre of a powerful coil, each time the current is broken a distinct tick is heard from the rod. If a file be placed in the circuit, so that a wire when it slides along will alternately close and open the circuit, the rasping noise of the wire sliding along the file will be distinctly rendered by the rod, each interruption giving rise to a tick; the series of ticks being in the same order exactly as the series of noises at the file. According to Wertheim, the tick is due to the sudden shortening which the rod experiences on being demagnetised. He shewed that at magnetisation the rod was lengthened but very slightly. According to Joule, if the rod be magnetised to saturation the lengthening amounts to $\frac{1}{27000}$th of its length. The tick is heard more distinctly if, instead of the rod, a piece of thin sheet-iron be rolled up so that its edges just overlap. The application of this magnetic sound to the conveying of musical sounds, is described under Telephone.

Current Induction.

116. *The fundamental law* of current induction may be thus shewn. Two long copper wires, *pp* (fig. 108) and *ss*, are fixed so as to be parallel and close to each other. The extremities of the one, *pp*, are in connection with the poles of a galvanic battery, E, and those of the other, *ss*, with the binding-screws of a galvanometer, G. The instant the circuit of the battery is completed, and the current sent along *pp*, a current in the opposite direction is induced in the wire *ss*, which is shewn by the deflection of the needle of the galvanometer. This induced current is only momentary, for though the current continues to circulate in *pp*, the needle soon falls back to its original position of rest, and the wire *ss* gives free passage to other currents, and appears to be in no way affected. If, now, when the needle is at rest, the battery circuit be broken, and the current in *pp* stopped, another momentary current is indicated by the galvanometer needle, but in this case in the same direction as the inducing current. The inducing wire and current are called *primary*, and are so distinguished from the induced wire and current, which are termed *secondary*. The passive condition of the wire while thus under induction has been described by Faraday as *electro-tonic*. An electric throb, so to speak, marks the setting in of this state, and another its vanishing ; the former in the opposite direction to that of the inducing current, and the latter in the same direction. If the primary wire, *pp*, be movable, so that it can be suddenly brought near to, and withdrawn from the secondary, *ss*, while the battery current passes steadily, currents are induced as in the former case, the approach of the wire being marked by an inverse current, and its withdrawal by a direct one. As long,

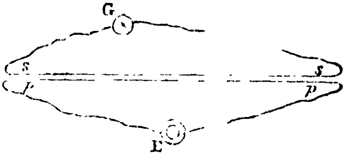


Fig. 108.

however, as the primary wire remains in any one position, all evidence of electricity in the secondary wire disappears; but if in this position the strength of the primary current should be increased or diminished, momentary currents in the secondary wire would again mark the changes in the primary, the increase causing an inverse, and the decrease a direct current. Hence we conclude, that *a current which begins, a current which approaches, or a current which increases in strength, induces an inverse momentary current in a neighbouring conducting circuit*, and that *a current which stops, a current which retires, or a current which decreases in strength, induces a direct momentary current in a neighbouring circuit.* For inverse, the word *negative*, and for direct, the word *positive*, are frequently employed in reference to induced currents.

117. In experiments like the above, it is much more convenient to wind the primary and secondary wires side by side round a bobbin, so as to form a coil, as in fig. 109. The wires are insulated from each other by a covering of wool or silk. Not only does such a disposition admit of very long wires being used, but it also disposes the wires employed to greater advantage, for each single turn of the primary wire acts not only on the corresponding turn of the secondary wire, but on all the turns near it. The inductive effect of such a coil is much greater than that which would be obtained by the same extent of wires running side by side in a straight or crooked line. It is not even necessary that the two wires be wound round together; each may be wound on a separate bobbin, and the one placed inside the other, as in fig. 110. The primary coil, P, here represented, is made of wire $\frac{1}{12}$th of an inch in diameter, covered with wool; and the secondary coil, S, of silk-covered wire, about $\frac{1}{80}$th of an inch, and much longer than the primary wire. With two such coils, the illustration of the preceding principles of induction can be conveniently given.

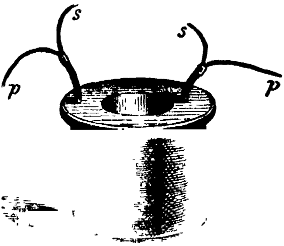


Fig. 109.

If the primary coil be placed in the circuit of a galvanic cell, by two loose and flexible wires, so as to allow of its easy motion, and if the terminal binding-screws of the secondary coil be placed in connection with a galvanometer, when P is inserted into S, a momentary inverse current is indicated, and

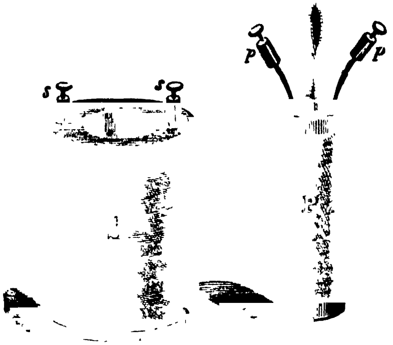


Fig 110.

when it is removed, a momentary direct one ; or if, when P remains in S, the strength of the primary current be altered, the needle announces the induction of currents according to the principles stated above. In order, however, to obtain the greatest effect from the secondary coil S, it is necessary, whilst P remains within it, to have some means of continuously completing and breaking the primary current. A contrivance for this purpose is called a *rheotome,* or *current-break.* A simple rheotome may be made of a common file, by holding one wire from the battery against the end of the file, and running the other along the teeth, the current being stopped each time the wire leaves a tooth. In this way, a rapid series of interruptions is effected, each of which is attended by an inverse and a direct current in the secondary wire. A break of the same description, but more constant, may be also made by causing a metal spring to press against the teeth of a metal wheel, both spring and wheel being connected with the battery. As the wheel is turned by a handle, the spring breaks the contact each time it slips from one tooth to another. The most convenient form of break, however, is one which is made self-acting by the action of an electro-magnet, which receives the name of a *magnetic hammer.* One form of this instrument is shewn in fig. 111.

118. *Quantity and Tension of Induced Currents.*—Let us place the coil P within S; let P, along with a self-acting rheotome, be put in the circuit of a galvanic cell, and let S be connected with a galvanometer. The interruption in the primary current being effected by the rheotome with great rapidity, the induced inverse and direct currents are sent with corresponding rapidity through the coil of the galvanometer. If this last be of a short and thick wire, so as not to tax the tension of the current transmitted, the induced currents will not deflect the needle; or if they should happen, through the unsteady action of the break, to do so, it only oscillates round its position of rest. This proves that *the quantity of electricity transmitted by the induced inverse and direct currents is the same,* for they each exert the same influence on the needles. But if the coil of the galvanometer consist of a long fine wire, the needle is kept deviated in a direction which argues the action of the direct current. This leads us to conclude, that *both currents, though equal in quantity, are unequal in tension, the direct current having the highest tension*, for it has more power to force its way through the fine wire of the galvanometer than the inverse. Other proofs of the same principles may be easily furnished.

It is found that *the electro-motive force of current induction* (other things being the same) *is proportional to the strength of the primary current, and to the number of turns in the secondary coil, but is independent of the conducting power of the metal of the secondary wire.*

The difference of the tension of the two induced currents is accounted for in this way: when a change takes place in the primary current, the quantity of the electricity induced by it in the secondary wire is the same whether this change takes place quickly or slowly; the tension, however, is very different. When the change takes place slowly, the total quantity of electricity in circulation continues to pass as slowly, and there is little in motion at one time; but when the same occurs quickly, it is sent with momentum, so to speak, and the quantity in circulation at one time is as much greater, in comparison with the former case, as the time is shorter. It is this quick dispatch of electricity which constitutes the tension of the current. Now, as it takes some time before the primary current is fully established, the inverse induced current is slow and of low tension; but when the contact is broken, the primary current ceases much more suddenly than it began, and the direct induced current is quick and of high tension. This view of the matter is borne out by experiment, for it is found that *whatever favours the suddenness of the changes of the primary current, heightens the tension of the currents induced by these changes.* The break, from this circumstance, forms an important element in the construction of all induction apparatus.

Iron Core of Primary Coil.—The inductive power of P, fig. 110, is immensely increased by putting a bar of soft iron in the heart of it, or, better still, a bundle of iron wires. The iron wires must be insulated, which is sufficiently effected by the rust that gathers on them. In a solid bar, currents are formed which impede the sudden cessation of the primary current. These, however, cannot be formed in the bundle of insulated wires. For the same reason, no tube of metal must be used in the construction unless it have a longitudinal slit in it, making the section of the tube a broken ring. The use of this iron-wire core in all induction apparatus, makes their effect more attributable to magneto-electric than purely current induction. The excitation of magnetism in the core is the principal aim of the primary coil, and as a strong current is essential to that object, it is made of thick wire and of moderate length. In the secondary coil, the tension of the induced current alone is aimed at, and with this view it is made of as thin wire as can be made, so as to admit of as many turns as possible being brought within the influence of the core and primary coil. The electric conformation of the secondary coil is sometimes looked upon in the same light as that of a galvanic battery. The total electromotive force of the coil is the sum of that of all the turns in it, in the same way that the electro-motive force of the battery is proportionate to the number of cells.

119. *Extra Current.*—Not only does a galvanic current induce electricity in a neighbouring circuit, but it also acts inductively on itself. When contact is broken in a battery circuit, the galvanic spark is seen. When the wire is short, the spark is feeble, but it increases in brilliancy with the length of the circuit, and this becomes particularly observable when the wire is wound round in a coil. This certainly does not arise from the current being strong with the long wire, and weak with the short one, for quite the reverse is the case, as might be shewn with the aid of a galvanometer. The real cause of the superior brilliancy of the galvanic spark with the long circuit is to be found in the induction of the primary current on the various parts of itself, exciting, as they are called, *extra currents* in the primary wire. It has been fully attested by experiment, that at the instant *a galvanic current begins and ends, extra currents are induced by the action of the several parts of its circuit upon each other, that at the beginning of the current being inverse, and that at the end direct.* As the extra current inverse acts opposite to the main current, it does not appear as a separate current, but only retards the instantaneous passage of the main current. The extra current direct succeeds the main current, and has consequently a separate existence. It is what is generally referred to when the extra current is spoken of. This extra current is of much higher tension than the original current. The effect of the extra current on the direct induced current of the secondary coil is to lessen very decidedly its tension. If a way be made for the extra current, the tension of the induced current falls prodigiously. In a large coil-machine, which gives freely sparks of one or two inches in length, when the two portions of the break are joined by a thin wire, so as to allow the extra current to pass, sparks will not travel between the two poles, however near they are brought. When no such communication exists, a portion of the extra current leaps over between the separating parts of the break, and in so far diminishes the intensity of the secondary current. The condenser of the coil-machine, to be afterwards described, has

for its object the absorption or suppression of the extra current, but the manner in which it effects this is not yet properly explained. The prejudicial effect of the extra current on the induced current is easily understood, when we bear in mind that it prolongs the cessation of the magnetism of the core and of the current in the primary coil, and thus impairing the suddenness of this change, reduces the tension of the induced current.

120. *Induction Coil.*—The essential parts of this apparatus have been already described in detail. A primary coil with its core of iron wire, and a secondary coil exterior to, and insulated from a primary coil, form the main portion of the instrument. The primary coil is connected with the poles of a galvanic battery, and in the circuit a rheotome is introduced, to effect the interruptions of the current essential to its inductive action. A commutator and condenser are also essential parts connected with the primary circuit.

The *rheotome* is shewn in fig. 111. A is an iron plate, into which the ends of the iron wires forming the core are fixed, and which serves as an anvil for the hammer H. H has for its shaft the stiff spring D, which keeps p back, and also forms part of the primary circuit. p is a little projecting nipple tipped with platinum, e is a screw, the end, p', of which is also tipped with platinum. C, an upright brass standard, also forms part of the circuit. When the circuit is closed, A becomes magnetic, and draws away H from p'. The primary circuit formerly closed at p and p' is now broken. A loses its magnetism, and H, under the influence of the spring D, is taken back to p'. The circuit is again closed, A again becomes magnetic, and thus H is kept oscillating with great rapidity between A and p', alternately opening and closing the primary circuit. b is a screw giving to D the necessary stiffness.

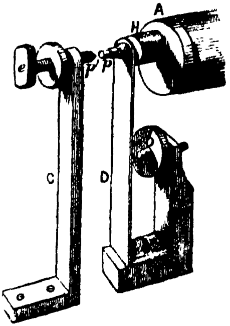


Fig. 111.

The *commutator* consists of a cylinder of ivory, with two brass plates attached to its sides, moving on a brass axis, supported by two brass standards. One axis does not go through the whole way, so that two distinct pieces of brass serve as an axis. One of the standards is connected with the +, the other with the – pole of the battery. Each plate communicates with one of the standards, so that the plates form the poles. A spring presses against the cylinder, either on the plates or on the ivory. These springs form part of the circuit; when the springs press against the plates the current flows, when the plates are reversed by a handle attached to the cylinder, the current is reversed.

The *condenser* consists of several sheets of tinfoil and oiled silk, laid alternately the one above the other. The first, third, fifth, &c. sheets of tinfoil are connected by strips of the same material; so are the second, fourth, sixth, &c.; the whole forming a condensing apparatus like a Leyden jar, the odd sheets forming the one coating, and the even sheets the other. Each set of sheets is connected with one of the wires of the primary coil. The condenser is generally placed in the sole of the instrument, and does not meet the eye.

An induction coil, as constructed by Ladd of London, is represented in fig. 112. The forms under which the instrument appears are very various, and the one in the figure only serves to shew the general requirements in its construction. The two binding-screws, *p* and *n*, are for the battery wires; C is the commutator. The two coils, W, lie horizontally on the sole of the instrument, S. The secondary coil alone is seen,

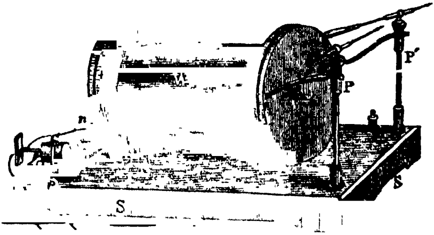


Fig. 112.

the primary being within it and out of view. The breaking hammer, being behind the coil, is likewise not shewn. The condenser is contained by the box which constitutes the sole, and a conducting connection is established between its coatings and the wires of the primary coil. The terminations of the secondary coil are fixed to the heads of the glass pillars, P, P′, which are furnished with pointed rods capable of universal motion. The excellence of the instrument depends on the proper insulation of the secondary coil. The bobbin must be made of glass, gutta-percha, or (best of all) vulcanite, so as to prevent the induced electricity from reaching the ground by the primary coil. Care must also be taken to insulate the different parts of the secondary coil from each other. If this were not done, the spark which completes the secondary current, instead of taking place at the rods, the place at which it is wanted, would pass within the coil itself. It is necessary, in consequence, to have each layer of the coil insulated from the other, by interposing gutta-percha paper, and cementing it with a hot iron to the sides of the bobbin. The induced current must thus pass through all the turns of the wire, and is prevented from shortening its course by leaping over one or more layers of the coil. (See page 265.)

121. *Experiments with the Induction Coil.*—Say that we experiment with a coil like the one shewn in fig. 112, about one foot long and nearly six inches in diameter, which yields readily sparks of from four to five inches with a battery of six Bunsen cells. After connecting the battery wires, and setting the commutator so as to complete the contact, let us place the movable rods within an inch of each other. An uninterrupted rush of sparks is transmitted between the points of the rods. The sparks are not the clear single sparks of the electric machine, but seem to be made up of several sparks occurring at the same instant, which are white and crooked. These are enveloped in a luminous haze, or aureole, which can be blown away by the breath, and thereby separated from the white spark which cannot be so removed. The aureole is repelled by the poles of a powerful electro-magnet, whilst the white spark is not affected by it. As the rods are withdrawn from each other, it disappears, and when they stand

above three inches apart, the spark resembles in every respect the forked single spark of a powerful electric machine. When the points are withdrawn beyond striking distance, electric brushes still play between them, which become visible in a darkened room. If the hand be brought near the rod connected with the exterior end of the coil, sharp stinging sparks, two or three inches in length, are got. The rod connected with the inner end does not yield them so readily, and this is the same whether it be the + or — pole. Each pole of the induction coil is the seat of two opposite electricities, alternating with each other, alike in quantity, but differing in tension, and this accounts for the resemblances and differences between the coil and machine electricities. A Leyden jar may be charged, but not to the same extent as by the electric machine, if one of the wires be connected with the outer coating, and the other brought within an inch of the knob. The jar on being removed may be discharged by the tongs (fig. 54). When the poles are put in connection with the coatings of a Leyden jar, and the points placed within half an inch of each other, the sparks passing between the points are much more brilliant, and the sharp snap of the simple spark grows into a loud report. The Leyden jar effects a condensation of the electricity of each direct current, and each spark discharge takes place in shorter time, and consequently with greater intensity. The *condensed spark* punctures paper and the like with great facility, but it is of very low heating power. The uncondensed spark, more particularly the hazy spark, got when the poles are near each other, kindles paper, gunpowder, coal-gas, and other combustibles, with great readiness. The power of the direct induced current of even large induction coils to deflect the magnetic needle, and to effect chemical decomposition, is very insignificant. This shews that it is very much inferior to the inducing current in quantity, however much it may be superior in tension. The physiological effect, on the other hand, is tremendous, and the experimenter must take care not to allow any part of his body to form the medium of communication between the poles, as the shock so got might be dangerous, if not fatal.

When the induced current is made to pass through nearly vacuous spaces, a very splendid effect is produced. The *electric egg* (fig. 113) is employed to display this. It consists of a glass vessel in the shape of an egg, with an open neck above, and another below. Brass fittings are attached to these. The lower opening is fitted with a stopcock, and can be screwed to the plate of an air-pump. A brass rod and ball rise a short way into the egg. The fitting above are intended to allow of a rod ending in a ball passing up and down air-tight, so that the two balls can be conveniently set at different distances. When the egg is exhausted, and the wires from the coil are attached, the one above and the other below, a luminous glow extends between the balls, which is wide in the middle, and contracts at either extremity. When the exhaustion has reached one-twelfth of an inch, as shewn by the gauge of the air-pump, black bands are seen to lie horizontally in the light, so as to wear the appearance of stratification, as shewn in the figure. These occur more readily when a drop or two of turpentine, alcohol, or ether have been introduced into the egg. The cause of the stratification is as yet a matter of speculation. The ball which forms the pole is enveloped in a covering of blue light. The glow, which is of a beautiful mauve tint, appears to proceed from the + ball, and reaches nearly to the - ball, from which it is separated by a well-marked non-luminous space. By means of the commutator, these appearances at the balls can be instantly transposed. Serving the same purpose as the electric egg, there is a great variety of *vacuum tubes* hermetically sealed and ready for use at any time. These having been first filled with particular gases, and then exhausted, exhibit lights of various tints, according to the gas contained by them.

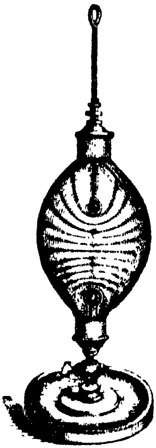


Fig 113.

Wright's Electric Cohesion Figures.—These are due to Dr

Strethill Wright (1863). A clean sheet of glass is laid on a plate of blackened metal, and a drop of liquid is placed on the middle of it. One of the poles of the coil is connected with the metal plate, and the other made to dip into the drop. When the coil is set in action, branches issue from the drop, and spread themselves over the plate. The shape of the figure thus formed is determined by the nature of the cohesion existing in the particles of the drop, and between the drop and the glass. Hence, when the various acids and solutions of salts are treated in this way, we obtain an endless variety of figures.

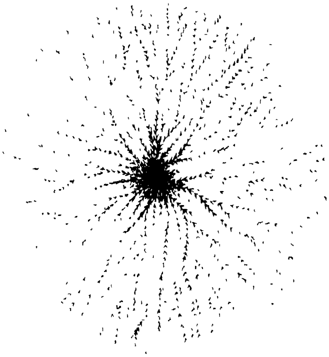


Fig 114.

Mica may be substituted for glass, the figures formed on it being even more various. A change in the figure is also got by reversing the pole. Fig. 114, drawn by Dr Wright, shews the + figure of cyanide of potassium on washed mica; a small coil giving a spark of $\frac{1}{8}$th of an inch can produce these figures. They may be also shewn by frictional electricity. Dr Wright has also obtained very large and fine figures by the electricity of cleavage. He places the drop on a clear surface of freshly split mica, and breathes on it, when it expands into a figure.

Conductivity of Flame.—When one wire of the coil is connected by a Bunsen lamp, and the other held six or seven inches above the mouth of the burner, no spark passes. When the lamp is lit, they pass readily, shewing flame to be a conductor. Let us now lift up the wire above the flame so that the sparks again cease to pass. When common salt is put into the flame, the sparks instantly reappear, shewing that the salt heightens the conducting power of the flame. The effect of salts in improving the conducting power of flame was first shewn by Dr Wright (1863).

Chronology of Current Induction.—The discovery of the power of electric currents to induce currents in neighbouring conducting circuits is due to Faraday. His researches on the subject, named by him *volta-electric* induction, were published in the Philosophical Transactions (1831—1832). Henry (1832) observed that when contact was broken in a long galvanic circuit a bright spark occurred, which did not occur when the circuit was short. This was shewn by Faraday (1834) to be due to the extra current induced by the various parts of the circuit on each other. Bachhoffner and Sturgeon (1837) shewed the superior action, in induction apparatus, of a bundle of iron wires to that of a solid bar of iron. Henry (1841) studied the inductive action of induced currents of different orders. Ruhmkorff constructed (1850 or 1851) the first so-called *induction coil*, the excellence of which was chiefly attained by the proper insulation of the secondary coil. Fizeau (1853) increased immensely the power of the coil, by providing it with a condenser. Of late years, coils of great power have been constructed, rivalling, if not exceeding, the most powerful electric machines in length and power of spark.

Magneto-Electric Induction—Magneto-Electricity.

Magneto-electricity includes all phenomena where magnetism gives rise to electricity. There are practically two cases of it, namely, when the current is induced in a coil of insulated wire, and when it is induced in conducting plates.

Currents induced by Magnets in Coils of Wire.

122. *How a Current is induced in a Coil by a Magnet.*—When a coil, in which a current circulates, is quickly placed within another coil unconnected with it, a contrary induced current in the outer coil marks its entrance, and when it is withdrawn, a direct induced current attends its withdrawal (117). Change, whether in the position or current strength of the primary coil, induces currents in the secondary coil, and the intensity of the induced current is in proportion to the amount and suddenness of the change. In singular confirmation of Ampere's theory, a permanent bar-magnet may be substituted for the primary coil in these experiments, and the same results obtained with greater intensity. When a bar-magnet is introduced into the secondary coil, a current is indicated, and when it is withdrawn, a current in a contrary direction is observed, and these currents take place in the directions required by Ampere's theory. A change of position of the magnet is marked by a current, as in the former case. If we had the means of increasing or lessening the magnetism of the bar, currents would be induced the same as those obtained by strengthening or weakening the current in the primary coil. It is this inductive power of iron at the moment that a change takes place in its magnetism, that forms the basis of magneto-electric machines. The manner in which this is taken advantage of will be easily understood by reference to fig. 115. NS is a permanent horseshoe magnet, and let us suppose it to be fixed; CD is a bar of soft iron, with coils A and B wound round its extremities, and may

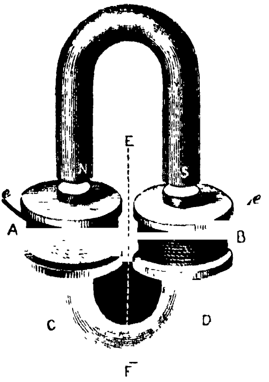


Fig. 115.

be looked upon as the armature of the magnet. CD is capable of rotation round the axis EF. So long as CD remains in the position indicated in the figure, no currents are induced in the surrounding coils, for no change takes place in the magnetism induced in it by the action of NS. The moment that the poles of CD leave NS the magnetism of the soft iron diminishes as its distance from NS increases, and when it stands at right angles to its former position, the magnetism has disappeared. During the first quarter-revolution, therefore, the magnetism of the soft iron diminishes, and this is attended in the coil (for both coils act, in fact, as one) by an electric current, which becomes manifest when the ends, *e*, *e*, of the coil are joined by a conductor. During the second quarter-revolution, the magnetism of the armature increases till it reaches a maximum, when its poles are in a line with those of NS. A current also marks this increase, and proceeds in the same direction as before; for though the magnetism increases instead of diminishes, which of itself would reverse the induced current, the poles of the revolving armature, in consequence of their change of position with the poles of the permanent magnet, have also been reversed, and this double reversal leaves the current to move as before. For the second half-revolution the current also proceeds in one direction, but in the opposite way, corresponding to the reversed position of the armature. Thus, *in one revolution of a soft iron armature in front of the poles of a permanent magnet two currents are induced in the coils encircling it, in opposite directions, each lasting half a revolution, starting from the line joining the poles.*

123. *Magneto-electric Machine.*—The general construction of a simple magneto-electric machine is shewn in fig. 116, which is one of the forms of Stöhrer's machines. NS is a fixed permanent magnet. BB is a soft iron plate, to which are attached two cylinders of soft iron, round which the coils C and D are wound. CBBD is thus the revolving armature, corresponding to CD in fig. 115. AA is a brass rod rigidly connected with the armature, and also serving as the rotating axle. F is a cylindrical projection on AA, and is pressed upon by two fork-like springs, H and K, which are also the

poles of the machine. The ends, *m*, *n*, of the coil are soldered to two metal rings on F, insulated from each other. When the armature revolves, AA and F move with it. F, H, and K are so constructed as to act as a commutator, reversing the current at each semi-revolution. By this arrangement, the opposite currents proceeding from the coil at each semi-revolution are so transmitted to H and K, that these retain the same names. But for this, the effect of the current derived from one semi-revolution would be reversed by that proceeding from the next. H and K, however, change names with the direction of the rotation of the armature.

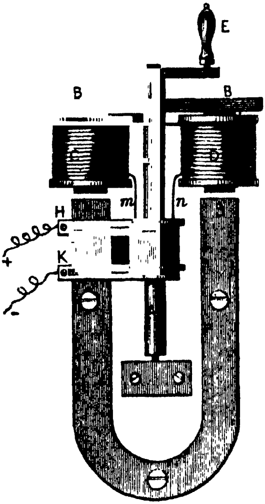


Fig. 116.

The commutating arrangement is shewn in fig. 117. A is the axis of the revolving part, the two black lines under H and K are the two forks of these springs, *a* and *f* are projections on a metal tube next the axis, and *c* and *e* are projections on another tube insulated by boxwood or vulcanite (shewn black in the figure) from the inner tube. Both tubes are fixed to the axis A, and move round with it. The projections *a*, *f*, *c*, *e* are half rings, *a* and *c* being on one side of the axis, and *e* and *f* on the other. Each tube has the end of one of the coil-wires attached to it, so that the tubes thus form the terminations of the coil. As shewn in the figure, the left-hand prong of H rests on *a*, and the left-hand prong of K on *c*;

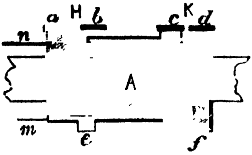


Fig. 117.

if *a* be +, *c* will be —. Suppose, now, the half-revolution finished, then *b* will be on *e*, and *d* on *f*, just when the current has begun to flow in the contrary direction, and the tubes have changed signs. Still, however, H is + and K —. When the armature is made to revolve with sufficient rapidity, a very energetic and steady current is generated, which possesses all the properties of the galvanic current. Compared with the galvanic battery, the magneto-electric machine is a readier, steadier, and cleanlier source of electricity, and is, in consequence, extensively used instead of it. Magneto-electric machines may be made of any strength by increasing the number of magnets and the mechanical force employed.

In the machine just described, the amount of electricity induced in the coils is at a maximum just when the armature is leaving the poles, and at a minimum when it stands equatorially. The gradual cessation of the magnetism of the core in the first quarter revolution, and the gradual acquisition of it in the second, prevents anything like an instantaneous stoppage and commencement of the current in the half-revolution. The current is thus tolerably continuous, and when the velocity is great, it is nearly uniform. Hence, when it is sent through the nerves of the body, which are affected by sudden changes of current tension (99), a slight effect only is felt. When, therefore, physiological effect is wanted, a break must be effected in the current. This is done in Stohrer's machines by making the half-rings overlap a little, so that, at the change of pole, when the current is strongest, the interpolar resistance consists only of the prongs of each fork resting on the two half-rings. As this resistance is indefinitely small, the whole of the current goes by it, and none of it by the body. When one prong of each fork leaves simultaneously its half-ring, the current then passes through the body; and as the resistance of this last is great, a partial stoppage of the current occurs at the instant of separation, which excites an extra current in the coils of the machine. The tension of the extra current is high, and powerfully affects the nerves. It is felt at each half-revolution.

In large machines, several magnetic magazines are employed with a corresponding number of armatures and coils. The coils may be arranged like the cells of a galvanic battery, for tension or for quantity. For tension, they are arranged successively, so that they form one compound circuit; for quantity, each single coil or set of coils contributes to the common current. The electro-motive force, resistance, and current strength are formed as for a galvanic battery (96). The thickness of wire is selected according to the object of the machine. For giving shocks, or effecting chemical decomposition, the wire must be long and thin; for heating platinum wire, thicker and shorter. The electro-motive force increases with the rapidity of rotation. Dove has found that in magneto-electric machines, where the current is primarily induced by magnetism, a solid iron core as an armature gives a better effect than a bundle of iron wires. (See also page 259.)

Chronology of Magneto-electric Coil-machine.—Faraday (1831) was the first to obtain a current from a coil by magneto-electric induction. Experimenting with a straight bar of iron as the core of a coil, he obtained opposite currents from the coil, according as the bar was made to approach the poles of a horseshoe-magnet or to recede from them; with the coil without the core he got the same result, though to a much less degree. Pixii (1832) invented the germ of the machine as now used. Improvements in the construction have since been introduced by Saxton (1833), Clarke (1836), Petrina (1844), Stöhrer (1844), and recently, by Siemens and Halske.

124. *Electricity induced by the Magnetism of the Earth.*—Faraday was the first (1831) to obtain electricity from the inductive action of terrestrial magnetism. Terrestrial electric induction may be shewn by such an apparatus as that sketched in fig. 118. If a coil, CC′, be made to rotate, as shewn in the figure, round a horizontal axis, and its ends directly connected with a galvanometer, it will be found that, starting from a certain position, for one half-revolution the needle is deflected one way, and for the other in the opposite way. Suppose the axis to lie at right angles to the magnetic meridian, and that we place the plane of the coil at right angles to the dipping-needle, as a starting-point, each half-revolution will occasion a current in an opposite direction. The reason of this is obvious. Through

the half-revolution one half of the coil ascends and the other descends, cutting the lines of magnetic force, which are parallel to the dipping-needle in different ways; opposite currents are thus induced in each half (112, 126), and these aid each other to form one current. The descending half has its

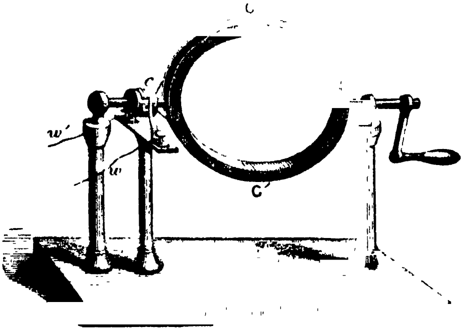


Fig. 118.

current tending eastward, and the ascending half westward. It is easy to see that by the intervention of a commutator, as at *c*, a current in one direction may be obtained through the wires *w*, *w'*. The maximum induction takes place when the plane of the coil is parallel to the dipping-needle, for then it cuts the lines of magnetic force at right angles. If the axis of the coil be placed horizontally in the magnetic meridian, the induced electricity will be wholly due to the vertical magnetic lines. If the axis be vertical, the same will be due wholly to the horizontal lines. A comparison of the deflection produced on the galvanometer by a similar rotation in these two positions may be used, according to Weber's suggestion, to determine the magnetic inclination, for (17) the tangent of the angle of inclination is equal to the vertical divided by the horizontal intensity. If the axis be parallel to the dipping-needle, no current will be obtained however fast the rotation. Palmieri, by means of a terrestrial induction machine, produced sparks, shocks, and the decomposition of water.

Currents induced by Magnets in Conducting-plates.

125. The *Magnetism of Rotation* was discovered by Arago in the years 1824–5. He observed that when a magnetic needle was made to oscillate immediately above a copper plate, it came sooner to rest than it did otherwise. The oscillations were made in the same time as when away from the plate, but they were less in extent; the plate seemed thus to act as a damper to the motions of the needle. This being the action of the plate at rest on the needle in motion, Arago reasoned that the needle at rest would be influenced by the plate in motion. Experiment confirmed this surmise. He made a copper disc revolve with great rapidity under a needle, resting on a membrane placed right over the disc, and quite unconnected with it, the middle of the needle being placed above the centre of the disc. As expected, the needle deflected in the direction of the motion of the disc. The deflection of the needle increased with the rapidity of the motion, and when it reached a sufficient amount, the needle no longer remained in a fixed position, but turned round after the disc. This action of the revolving disc was attributed to what was then called the 'Magnetism of Rotation,' and the name has been since retained. The explanation of this phenomenon was first given by Faraday (1831). He proved it to arise from the reaction of currents induced in the plate in motion by the magnet.

126. The magnetism of rotation is only one of a very large class of phenomena, in which the motion either of a magnet or a wire conveying a current induces a current in a neighbouring conductor. Lenz very conveniently sums up the law, holding in all such cases, in the following words: *When a current is induced in a conductor by the motion of a magnet or current, or of the conductor, the current induced flows in such a direction that its action opposes the motion producing it.* To take the simplest case, that of two parallel wires, in one of which a current circulates; let us bring either wire near the other, an opposite current will be formed in the wire where no current was at first (provided the circuit be complete), the mutual action between which and the

primary current will be to cause repulsion, and impede the motion of approach. If we separate the wires, the opposite will take place. In all the cases of attraction and repulsion in electrodynamics the same holds. Lenz's law may be thus otherwise put; when a conductor moves relatively to a current or magnet, or *vice versâ*, the directions of the inducing and induced currents are the reverse of what they would be if the same motion took place under the action of two primary currents, or a primary current and a magnet.

With the aid of Lenz's law, we can easily understand the principles at work in Arago's revolving plate. Fig. 119 represents what takes place in it. The plate, P P, may be regarded as divided into four parts; those of which *n*, *n'*, *s*, *s'* form the centres. The part *n* approaches the north pole, N, of the magnetic needle, NS. In order to impede the motion of approach, *n* must be forced to assume north polar magnetism, the current of which moves, as shewn in the figure, from right to left. The part of which *n'* is the centre, leaving a south pole, will be induced to assume north polar magnetism to impede the rotation of the disc. The currents of *n* and *n'* are coincident at their further ends, but in the middle, as shewn by the dotted lines, they are opposed, the result of which is that one current circulates, as shewn by the continuous line in the left-hand side of the plate. A similar state of things is also found in the right-hand half, as shewn in the figure. The two main currents are coincident in the middle of the plate. It is this conjoined current which affects the needle; it runs in a direction a little in advance of the needle, as the inductive power of the magnet takes some time to act. As the induced current lies below the needle, the deflection, according to Ampere's rule, takes place in the direction of the motion of the disc. If the disc were stationary, the currents induced in the plates would manifestly impede the oscillations

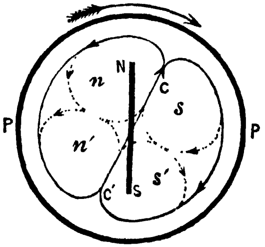


Fig. 119.

of the needle. When cuts are made in the disc in the line of the radii, it loses almost entirely its disturbing power; the currents formed in the whole disc can no longer take place, and those formed in the various sectors are weak in comparison; by filling up the vacant spaces with solder, the power is nearly restored to it. As is to be expected, the effect of the revolving plate depends on the conducting power of the material of which it is made. It is owing to its high conducting power that copper is so much used in these experiments; hence, also, it is that copper is so much employed in the construction of magnetic apparatus. A copper compass-box, for instance, is not only desirable, from its being free from iron, but it acts also as a damper to bring the needle quickly to rest when disturbed.

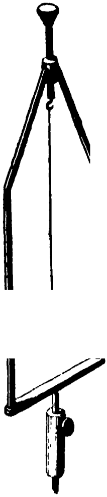


Fig. 120.

127. Lenz's law is applicable to all cases when electricity is induced by the motion of a magnet, or of a conducting circuit. It explains the magneto-electric machines already described. We may quote only two other experiments as illustrations of it. In the first experiment, a small cube of copper (fig. 120) is hung by a thread to a frame, and placed between the poles of a powerful electro-magnet; the cube is sent into rapid rotation by the twist on the thread, previously given it; it is instantly brought to a halt, when the current is allowed to circulate in the coils of the magnet, and it begins its motion again when the current is turned off. In the second experiment, a disc of copper (fig. 121) is made to rotate rapidly between the poles, *n*, *s*, of an electro-magnet, by means of a handle and intervening wheel-work turned by the experimenter. When the

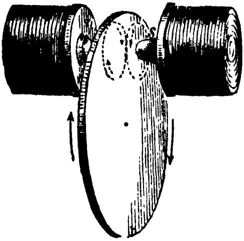


Fig. 121.

current invests the soft iron poles with magnetism, the disc, moving freely before, appears suddenly to meet with an unseen resistance, and the rotation continues slowly or not at all. If persisted in, the rotation causes the disc to rise in temperature, *the rise being proportionate*, according to Foucault, *to the square of the velocity of rotation.* As shewn in the figure, the approaching part of the disc has a south pole turned to *s* and a north pole to *n*. The receding part manifests the opposite polarity, both polarities combining to resist the motion of the disc. The currents marked with dotted lines are not the only currents. There are several such currents in the same direction, extending out like waves on each half, coinciding in the line between the centre and the poles. Hence if a circuit were formed, including the radius between the centre and the two poles, a current in one direction would be constantly transmitted through it. This may be done by connecting a wire with the axis of the plate, and by making a spring press on the edge of the plate, at the poles, so as to absorb the current without impeding the plate. To the spring a wire must also be attached. The two wires being connected with a galvanometer, a current in one direction would be indicated by it as the plate revolves. A machine of this kind, invented by Faraday, was the first form of the magneto-electric machine (1831).

Measurement of Current Elements in Absolute Units—Work and Heat Produced by the Current.

128. This system aims at measuring the current elements, electro-motive force, strength, and resistance, in terms of the absolute units of time, space, and mass. It is the most natural and rational system, and, for recording results, it will no doubt eventually take the place of all others. The British Association have adopted a unit of resistance, so as to facilitate its general introduction. In the Transactions of the

Association for the years 1862-3-4, the subject is treated at length. Here we can only give a general idea of the system, and shew how it is practically applied.

Definitions of Electro-magnetic Units.—In any absolute system the unit force is defined as producing unit velocity in a unit of mass in a unit of time. In the British Association system the *unit force* is that which is capable of generating in the mass of one gramme a velocity of one metre per second. At Paris, gravity generates in the mass of one gramme a velocity of 9·808 metres per second, so that there a unit of force is equal to $\frac{1}{9\cdot808}$ of the weight of a gramme. At London, gravity is 9·811 metres, so that the mass weighing a gramme at Paris would weigh more than a gramme at London, in the proportion of 9·811 to 9·808. Of course, if a gramme weight were brought over from Paris to London, it would still be looked upon as a gramme, but its downward force, absolutely considered as tested by a very delicate spring balance, would be greater. The same absolute downward force is got by a less mass at London than at Paris. Practically speaking, we estimate at London the mass of a gramme by counterpoising a gramme weight brought from Paris in an ordinary balance, so that the mass of gramme at London is the same as at Paris, although its downward force expressed in the units just defined is different. Masses being measured by relative weights, are comparable all over the world; but their weights or downward forces, arising from the action of gravity on them, are not, and must be expressed in absolute units to be comparable. The system we are describing demands that all local observation be expressed in an absolute or general standard, so that when so expressed they may be at once compared. To save explanation, we may, however, look on gravity as constant, and as that at London, results being expressed absolutely, though the data giving them be local. The weight of a gramme is thus equal to 9·811 units of force. A *unit of work* is a unit of force overcome through one metre: it is therefore $\frac{1}{9\cdot811}$ of the weight of a gramme raised one metre, or a gramme-metre. A *unit of heat* is the quantity required to raise the temperature of one gramme of water at its maximum density by 1° C. According to Joule, a unit of heat, when converted into work, is (at Manchester) capable of raising 423·5 grammes weight one metre. A unit of heat is, therefore, equivalent to 423·5 × 9·811, or 4155 units of work.

129. *A unit pole* is one which, at a metre distance, repels a similar unit pole with a unit of force. The mass of the unit pole is that of a gramme. Here only one pole of a magnet is referred to, the other being considered either to lie out of the way, or to be so similarly affected in the opposite way, as to act in combination with the pole in question. *A unit magnetic field* is that in which a unit pole is repelled with a unit of force. At that part of the earth's surface where the horizontal intensity is unity, the unit pole, if free to move in a horizontal plane, would acquire a velocity of one metre in a second. At London, the horizontal intensity is such that the unit pole would acquire a horizontal velocity of 1·764 metres per second.

A unit current is one which, in a wire one metre long, bent so as to form an arc of a circle of one metre in radius, or, which is the same thing, an arc of 57¼°, would repel a unit pole at the centre of the circle with a unit of force. The whole circumference of a circle, a metre in radius, is 6·2832 metres, and would consequently repel a unit pole at its centre with 6·2832 units of force. If such a circle be placed in the magnetic meridian, the deflection produced by it on a small needle at its centre, as in the tangent galvanometer, is due to the whole circumference, so that the strength of the current, measured by only one metre of it, forms only $\frac{1}{6{\cdot}2832}$ part of the deflecting force. A unit current in a straight wire, measuring a metre, repels another similar unit current, one metre distant, with a unit of force. A unit magnetic field repels a metre's length of a unit current held at right angles to the lines of magnetic force with a unit of force. Hence in a unit magnetic field, a metre of a unit current, forming an arc of 57¼°, and held in the magnetic meridian, would cause a small needle at its centre to deflect 45°.

130. *How an Electric Resistance may be expressed as an Absolute Velocity.*—Suppose, at any part of the earth's surface, two rails are placed parallel to each other, so that the plane

passing through them shall be perpendicular to the magnetic meridian, or to the lines of horizontal force. We may thus put the rails horizontally, the one lying right above the other. Suppose now that a rod, standing vertically, connects these rails, and can be slid along without friction between them. Let the ends of the rails at either termination be connected with a rod of equal length to the slider, and let it be placed in the magnetic meridian, or at right angles to the plane in which the slider moves. Let this rod be bent so as to form an arc of 57¼° of a circle, the radius of which must be the length of the rod or of the slider, and let a small needle be suspended at the centre. There will be thus a complete conducting circuit formed by one rail, the rod, the other rail, and the slider. Let the resistance, moreover, throughout this circuit be the same, whatever the position of the slider in the rails, or, which is the same thing, let the rails be perfect conductors. When the sliding rod is moved, it cuts the horizontal lines of magnetic force at right angles, and a current is induced by them in it (112, 126), the strength of which is proportionate to the number of lines cut by it in a given time. The faster, therefore, the rod moves, the greater is the current, and the greater will be the deflection of the small needle. When it is moved with such a velocity that the needle deflects 45°, the current in the arc has acquired the same power over the needle as the earth's magnetism. The current induced in the slider is in such a direction that the vertical action between it and the earth's magnetism offers resistance to its further motion, and work therefore has to be expended to move the slider. The work expended in a given time, say a second, in moving the rod, is within the circuit equivalent to the electro-motive force, or the work done in producing the current. If the resistance within the circuit which the electro-motive force has to overcome in generating a current capable of causing a deflection, say of 45°, be small, the velocity of the slider will be correspondingly small; if great, correspondingly great. The velocity of the slider thus measures the resistance of the circuit.

Although this arrangement, which contains the germ of the reasoning, cannot be practically carried out, other arrangements can by calculation be reduced to it. To fix our ideas, let the slider be a metre in length; let it move, say, 10,000 metres per second to cause a deflection of 45°—that is, to generate a unit current in the supposed circuit. The slider, in moving at this rate, describes an area of 10,000 square metres, and this is the measure of the number of lines of force cut, or of the inductive power of the earth's horizontal magnetism in the experiment, and it may be obtained, as in this case, by a slider of a metre in length moving at the rate of 10,000 metres per second, or one 100 metres in length moving with $\frac{1}{100}$th part of the velocity—that is, 100 metres. Suppose, now, I wish to know the resistance offered by a wire of a certain thickness, expressed as a velocity, I bend 6·2832 metres of it into the form of a ring of one metre in radius, and make the ring capable of rotation round a vertical, as it is in fig. 118, round a horizontal axis. The induction to which the ring is subjected in its rotation, causes two opposite currents to traverse it in one revolution, the turning point being when the ring is at right angles to the magnetic meridian; but since each half changes its side with each change of current, to an observer north or south of the ring the current appears to move always in the same direction, and it consequently affects a needle placed at its centre in the same way. To reduce the motion of the ring to the equivalent motion of the slider, we must project the motion of the ring on a vertical plane at right angles to the magnetic meridian (112). The semi-revolution of the sphere described by the ring projected on this plane is the area included by the ring, namely, 3·1416 square metres, and by a whole revolution twice this, or 6·2832 square metres. If ten revolutions per second produce a deflection of 45°, the effective area is 62·832, which is equivalent to a metre slider moving at the rate of 62·838 metres per second. But we reckon the current from one metre of it, so that the velocity of the ring must be 6·2838 times increased to give one metre the effect of the whole circumference: the equivalent velocity of the metre slider must thus be 394·7. The resistance of 6·2832 metres of the wire in question is thus 394·7 metres per second, and we can easily calculate the length of it necessary to produce a resistance of one metre, or of 10,000,000 metres, the B. A. unit (94). Here we have only given the mere outline of the process of estimating resistance as an absolute velocity. It was essentially by this method, which is due to Professor Thomson, that Messrs Maxwell, Stewart, and Jenkin (1863–4), with almost perfect experimental and mathematical skill, measured the absolute resistance of a coil instead of a ring of copper wire, and thence obtained a material value for a B. A. unit. Should the material standard they found be lost or damaged, it could be again renewed by a new determination. The obtaining of a material from an abstract or ideal standard is nothing practically new, for our measures are got from the length of the seconds pendulum at London, which requires as much care and skill in its determination as the B. A. unit.

131. *Relations of the Current Elements to Work.*—A resistance, accordingly, we express as a velocity. Suppose, now, our metre slider moves with a velocity l per second, and that a current of the strength, s, is produced in a magnetic field of the intensity h, then the work, w, expended per second in moving it through l metres per second will be the velocity, l, multiplied by the product of the current s, and the intensity of the field h, or $w = lsh$. Now, when l measures the resistance of the circuit, s equals h, then $w = s^2l$; that is, the work done per second by a current s, in a resistance l, equals the square of the current multiplied by the resistance. We know from Ohm's law (95) that e, the electro-motive force, is equal to ls. Hence $w = es$, or $e = \frac{w}{s}$; that is, the electro-motive force is equal to the work done per second divided by the strength of the current.

According to any absolute system, a unit of electro-motive force is capable of transmitting a unit current against a unit resistance in a unit of time. According to the British Association system, a unit of electro-motive force is thus capable of overcoming a unit of force through 10,000,000 = 10^7 metres in a second, or of performing 10,000,000 units of work in that time. 10^7 electro-magnetic units of work are equivalent to $\frac{1}{9{\cdot}811}$ part of 10^7 grammes in weight raised one metre, or 1,019,200 gramme-metres. A unit of work is $\frac{1}{9811}$ part of a unit of heat; hence the unit electro-motive force in a circuit of resistance one, produces in one second $\frac{1}{4155}$ of 10^7, or 2406·7 units of heat, or as much heat as will raise 2406·7 grammes of water 1° C. It is found also by experiment, that a unit current can, per second, decompose 0·0092 grammes of water, or generate 17·2 cubic centimetres of explosive gas at the temperature 0° C, and under a barometric pressure of 760 millimetres. This is called *the electro-chemical equivalent of water.* As the chemical equivalent of water is 9 and of zinc 32·5 in each cell of a battery generating a unit current, 0·0332 of a gramme of zinc is dissolved per second, apart, of course, from local action. A resistance is thus expressed in a velocity, a current in units of force, and electro-motive force in units of work.

132. *Practical Application of the Absolute System.*—Two things are necessary to apply the absolute system—a tangent galvanometer, and the determination of the horizontal intensity of the earth's magnetism, expressed in units of force, at the place of observation. This last for London was (January 1865) 1·764. The formula for the tangent galvanometer can be easily adapted to this system. T, in fig. 82, represents the horizontal intensity. In the position that the needle takes up, the portion of the horizontal intensity acting is T sin. d, and this multiplied by ML, the magnetic moment of the needle, gives its whole turning force on the needle, M being the strength of one of the poles, and L the distance between the poles. The electro-magnetic effect of the ring is represented by C, and in the deflected position of the needle the resolved part acting is C cos. d; this, again, must be multiplied by ML to give the turning force on the needle. Thus, CML cos. d = TML sin. d, or C = T tan. d. But C gives the force of the whole circumference. From this we must get the effect of one metre of the current bent into an arc of a circle one metre in radius. If R be the circumference of the ring, or the length of the wire coiled into a ring—for frequently the tangent galvanometer is constructed with a coil of wire instead of one ring—then as this acts at a distance equal to r, the radius of the coil, $C = \frac{R}{r^2} S$, or S (strength) $= \frac{r^2}{R} C$. Thus, S =

$\frac{r^2\,T}{R}$ tan. d. When there is only one wire as in the galvanometer described, $S = \frac{r \times T}{6·2832}$ tan. d.

In the instrument described in art. 96, $r = 0·21$ metre; thus, at London, $S = \frac{0·21 \times 1·764}{6·2832}$ tan. d. If the current be such as to make d 45° (tan. = 1), S will be 0·05895 units of force, which is what one metre of it can effect on another unit current, or on a unit pole situated as already mentioned. This current, in one unit of resistance, produces $(0·05895)^2 \times 10^7$ 34751 units of work per second. In a stationary wire, however, this work cannot be performed, so that it takes the form of heat. The units of heat generated by it are $(0·05895)^2 \times 10^7 \div 4155 = 8·3636$; that is, that the heat produced per second by this current in a unit of resistance is capable of raising the temperature of 8·3615 grammes of water 1° C. in a second. This current will also decompose $0·05895 \times 0·0092$ grammes of water per second, or 60·8 cubic centimetres of gas per minute. On comparing the results on this system and that of the electro-chemical units adopted in art. 96, it must be borne in mind that the whole electro-magnetic effect of the ring was coupled with 60 cubic centimetres per minute in the expression $S = 60 \times$ tan. d; whereas in the absolute system, which requires that 57¼° of the ring produce the deflection of the needle, this expression would be $S = 60 \times \frac{\text{tan. } d}{6·2832}$, S in the former is therefore 6·2832 times S in the latter system.

Let us now ascertain in absolute units the electro-motive force and liquid resistance of the Bunsen cell mentioned in art. 96. With no interpolar resistance, the strength of the current, as shewn by the galvanometer ($d = 53\frac{1}{8}°$) is 0·07860, and with one B. A. unit interposed ($d = 12\frac{1}{2}°$) 0·0131; consequently, by Ohm's law, $0·0786 = \frac{e}{l}$, and $0·0131 = \frac{e}{l + 1}$, whence $e = 0·01572$ of the B. A. unit of electro-motive force (10^7 units of work per second), and $l = 0·2$ of a B. A. unit of resistance (10^7 metres per second). The electro-motive force of Daniell's cell, the most constant of all, is given by Joule as 0·01073, and by Bosscha, who adopts it as a unit of electro-motive force, as 0·010258 of a B. A. unit. Both of these rather exceed the value given in article 85, which is, on reduction, 0·0094.

The system of absolute measurement is entirely due to Professors Weber and Sir William Thomson. Weber (1851) first proposed a system of absolute measurement; the suggestion was immediately taken up by Sir William Thomson (1851), and the relations of the current to work in the system were first shewn by him.

THERMO-ELECTRICITY.

Thermo-electricity treats of the currents that arise from heating the junction of two heterogeneous conductors. Such currents can be obtained in many ways, but we shall here simply indicate the more important.

133. *Thermal Currents with one Metal.*—Take a copper wire, cut it in two, and fix each half in one of the binding screws of a galvanometer. Heat one of the free ends to redness, and press it against the other, and a current will be generated, passing at the junction from the hot to the cold end, as shewn by the deflecting needle. The same production of a current by heating one piece of wire, and bringing it in contact with a cold piece of the same, is more decidedly shewn with two pieces of the same platinum wire attached to the binding-screws of the galvanometer. To increase the surfaces of contact, the free ends of these wires are coiled into flat spirals. One of the spirals is heated to redness, and pressed on the other. A current is then formed, passing from the hot to the cold wire. In almost all cases where portions of the same metal at different temperatures are pressed together a current is produced, the direction of which depends on the metal, and even on the structure of the same metal.

Currents are also obtained when two portions of the same metal or piece of metal have different structures, and the point where both structures meet is heated. If, for instance, one piece of wire be hard-drawn and the other part annealed, when the seat of change from the one to the other is heated, a current is produced. Thus, if a hard-drawn wire of brass be partly annealed, and the separation between the two parts be heated, a current passes at the junction from the soft to the hard part. Or if the whole be annealed, and one part of it be hammered, the hammering makes the other part harder, and the current, when the junction is heated, passes from the soft to the hard part. The direction of the current differs with different metals in these circumstances. Even the difference of structure introduced by the twisting of a portion of a wire, causes a current to flow when the wire is heated in the vicinity of the twist. Thus, when a knot is tied on a platinum wire, or when part of it is coiled into a spiral, a current passes always towards the knot or coil when the flame of a spirit-lamp is directed on a portion of the wire near the knot or spiral. The twisting, in this case, acts as hardening or hammering would do. By running the flame of a spirit-lamp along a metal, it frequently happens, more especially if it be of a crystalline structure, that currents are produced at certain points. These points are supposed to indicate a change in structure. If a bar of fused antimony have its ends connected with a galvanometer, and examined in this way, *neutral points* are generally found. The flame of a lamp generates a current near these points, always passing towards the point, and changing in direction with the change of the side on which the flame is applied. Bismuth shews neutral points, but the current always goes from the cold to the hot part across the neutral point. In bars of these metals which are crystallised regularly and slowly, no neutral points are found.

134. *Thermal Currents with two Metals.*—A current is always obtained when the point of junction of any two metals is heated. The two metals which shew this property in the greatest degree are bismuth and antimony. When a bar of antimony, A (fig. 122), is soldered to a bar of bismuth, B, and their free extremities are connected with a galvanometer, G, on the junction being heated, a current passes from the bismuth to the antimony as shewn in the figure. When S is chilled by applying ice, or otherwise, a current is also produced, but in the opposite direction. Such a combination constitutes a thermo-electric pair. Applying the same mode of explanation to this pair that we applied to the galvanic pair (64), bismuth is + within and – without the pair, antimony – within and + without the pair. Bismuth thus forms the – pole, but + element; antimony the + pole, but – element of the pair. The metals may be classed in thermo-electric just as they were in electro-

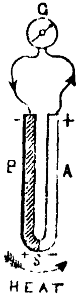


Fig. 122.

chemical order. The following table gives them in this order, the direction of the arrow shewing how the current goes within the pair:

HEAT.

- - - - - - →

Bismuth,	25
Cobalt,	9
Potassium,	5·5
German Silver,	5·2
Nickel,	5
Sodium,	3
Mercury,	2·5
Aluminium,	1·3
Magnesium,	1·2
Lead,	1·03
Tin,	1
Copper,	1
Platinum,	·7
Silver,	0
Gas Coke,	−·05
Zinc,	−·2
Iron,	−5
Antimony,	−10
Tellurium,	−179

←——————

COLD.

The order and numbers in this table are those given by Dr Mathiessen. The numbers give the relative electro-motive forces, and are calculated on the scale of copper-silver as unity. The greater the difference between the two numbers, the greater the electro-motive force. When two metals with the same sign are associated, the difference of the numbers gives the electro-motive force of the pair, with different signs the sum. Thus the electro-motive force of a bismuth and antimony pair is 25 − (− 10) = 35; of bismuth-copper, 25 − 1 = 24; of iron-antimony, − 5 − (− 10) = 5. Tellurium, from its rarity, cannot be practically employed. The structure and purity exercise an important influence on the electro-motive force. The numbers of bismuth and antimony in the table are given for those metals when cast. Commercial pressed wire of bismuth would stand as 36, and antimony as − 2. Temperature has also an important influence in determining this table. The order and numbers given are for temperatures between 40° and 100° F. For other temperatures, the table would be different for several of the metals.

It will be seen that metals like bismuth and antimony, which have a crystalline structure, are best suited for a thermo-electric pair. We found (26) that tourmaline, when heated, shewed an opposite electricity at each end. If it had a low conducting power like the metals just named, we might expect from it a thermo-electric current instead of mere polarity. It is probable that the crystalline structure, however, accounts for the appearance of electricity in both cases.

Thermo-electric Battery.—One bismuth-antimony pair is very little power. To increase this, several pairs are associated together, as shewn in fig. 123, where the same tension-arrangement is adopted as in a galvanic battery. The heat in this case must be applied only to one row of soldered faces. The current effect depends on the difference of temperature of the two sides. When a strong current is required, the one series must be kept in ice or in a freezing mixture, whilst the other is exposed to heat radiating from a red-hot plate of iron. As in the galvanic pair, the electro-motive force is proportionate to the number of pairs; the size of the bars, like the size of the galvanic plates, merely aiding to diminish the resistance. The electro-motive force of a thermo-electric battery is small; according to Dr Mathiessen, that of 25 bismuth-tellurium pairs equalling one cell of Daniell's battery when the one series is kept at 32° F. and the other at 212° F. In consequence of the low electro-motive force of the thermo-electric battery, the galvanometer to be used with it must introduce as little resistance as is consistent with the best effect on the needle. Hence special galvanometers are used, in which the coil wire is short (200 turns) and thick ($\frac{1}{25}$ inch); these are called thermo-galvanometers.

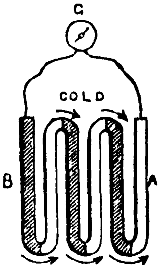


Fig. 123.

When a great number of pairs are formed into a battery, they may be conveniently arranged as in fig. 124, which shews one of 30 pairs. The odd faces, 1, 3, 5, &c., are exposed on the one side, and the even faces, 2, 4, 6, &c., on the other.

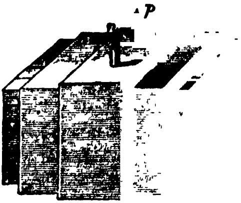


Fig. 124.

The terminal bars are connected with the binding screws *n*, *p*. The interstices of the bars are filled with insulating matter (gypsum) to keep them separate, and the frame in which the whole is placed is of non-conducting matter. Such a pile in conjunction with a thermo-galvanometer forms a most delicate thermometer for radiant heat. When placed in a room, the temperature of which is equable all round, no current is produced; but if heat be radiated more on one side than another, a current ensues. If the hand, for instance, be brought near on the one side, a current indicates its radiant power; or if a piece of ice be brought near, a current is also shewn, but moving in the opposite way.

135. *Thermal Effects produced by the Galvanic Current.*—As heat or cold produces a current at the junction of two dissimilar conductors, we would expect that if a galvanic current be made to pass through the junction, heat or cold would follow, and such is found to be the fact. When a current from a voltaic cell, passing, as shewn in fig. 125, through a system of three rods of bismuth, antimony, and bismuth, at the junction, where the current passes from bismuth to antimony, cold is produced; and at the other, from antimony to bismuth, heat. If, for instance, water be placed in a hollow at either junction, cooled to 32° F., it will become frozen when the current passes from the bismuth to the antimony. When the junction of these two metals is put into the bulb of an air thermometer, so that a current can be sent through it in either way, the air expands when the current goes from antimony to bismuth, but contracts when it goes in the opposite way. Powerful currents must not be used, otherwise heat will be produced at all the junctions.

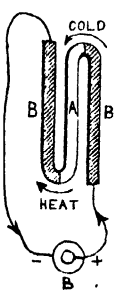


Fig. 125.

Seebeck was the discoverer (1821) of thermo-electricity; Nobili invented the thermo-electric pile (1834); Peltier (1834) first observed the thermal effects of galvanic currents at the junction of heterogeneous conductors.

PRACTICAL APPLICATIONS OF CURRENT ELECTRICITY.

Electro-Metallurgy.

136. Electro-metallurgy (Fr. *galvanoplastic*, Ger. *Galvanoplastik*) is the art of depositing, electro-chemically, a coating of metal on a surface prepared to receive it (102, 105). It may be divided into two great divisions—electrotype and electro-plating, gilding, &c.—the former including all cases where the coating of metal has to be removed from the surface on which it is deposited, and the latter all cases where the coating remains permanently fixed. Gold, platinum, silver, copper, zinc, tin, lead, cobalt, nickel, can be deposited electrolytically.

Electrotype—the art of copying seals, medals, engraved plates, ornaments, &c., by means of the galvanic current in metal, more especially copper. The manner in which this is done will be best understood by taking a particular instance. Suppose we wish to copy a seal in copper: an impression of it is first taken in gutta-percha, sealing-wax, fusible metal, or other substance which takes, when heated, a sharp impression. While the impression—say, in gutta-percha—is still soft, we insert a wire into the side of it. As gutta-percha is not a conductor of electricity, it is necessary to make the side on which the impression is taken conducting; this is done by brushing it over with plumbago by a camel-hair brush The wire is next attached to the zinc pole of a weakly charged Daniell's cell, and a copper plate is attached by a wire to the copper pole of the cell. When the impression and the copper plate are dipped into a strong solution of the sulphate of copper, they act as the – and + electrodes. The copper of the solution begins to deposit itself on the impression, first at the black-leaded surface in the vicinity of the connecting wire, then it gradually creeps over the whole conducting surface. After a day or two, the impression is taken out; and the copper deposited on it, which has now formed a tolerably strong plate, can be easily removed by inserting the point of a knife between the impression and the edge of the plate. On the side of this plate, next the matrix, we have a perfect copy of the original seal. If a medal or coin is to be taken, we may proceed in the same way, or we may take the medal itself, and lay the copper on it. In the latter case, the first cast, so to speak, that we take of each face is negative, shewing depressions where the medal shews relief; but this is taken as the matrix for a second copy, which exactly resembles the original. The adhesion between the two is slight, and they can be easily separated. The cell of a battery is not needed to excite the current. A galvanic pair can be made out of the object to be coated and a piece of zinc. Fig. 126 shews how this may be done. B is a glass vessel, containing sulphate of copper; A is another, supported on B by a wire frame, and containing a weak solution of sulphuric acid. The glass vessel, A, is without a bottom, but is closed below by a bladder. A piece of zinc, Z, is put in the sulphuric acid, and a wire, D, coated with insulating varnish, establishes a connection between it and the impression, C, which is laid below the bladder. Electrotype is of the greatest importance in the arts; by means of it, engraved copper plates may be multiplied indefinitely, so that proof-impressions need be no rarity; wood-cuts can be converted into copper; bronzes can be copied; and several like applications are made of it too numerous to mention. By connecting a copper plate ready for corrosion with the + pole, and making it a + electrode, it can be etched with more certainty than with the simple acid, and without the acid fumes.

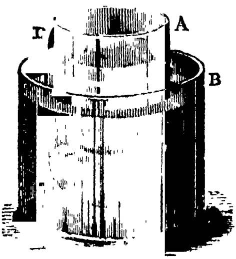


Fig. 126.

137. *Electro-plating.*—This is the art of coating the baser metals with silver by the galvanic current. It is one theoretically of great simplicity, but requires in the successful application of

it very considerable experience and skill. Articles that are electro-plated are generally made of brass, bronze, copper, or nickel silver. The best electro-plated goods are of nickel silver. When Britannia metal, iron, zinc, or lead are electro-plated, they must be first electro-coppered, as silver does not adhere to the bare surfaces of these metals. Great care is taken in cleaning the articles previous to electro-plating, for any surface impurity would spoil the success of the operation. They are first boiled in caustic potash, to remove any adhering grease; they are then immersed in dilute nitric acid, to dissolve any rust or oxide that may be formed on the surface; and they are lastly scoured with fine sand. Before being put into the silvering bath, they are washed with nitrate of mercury, which leaves a thin film of mercury on them, and this acts as a cement between the article and the silver. The bath where the electro-plating takes place is a large trough of earthenware or other non-conducting substance. It contains a weak solution of cyanide of silver in cyanide of potassium (water, 100 parts; cyanide of potassium, 10 parts; cyanide of silver, 1 part). A plate of silver forms the + electrode; and the articles to be plated, hung by pieces of wire to a metal rod lying across the trough, constitute the – electrode. When the plate is connected with the copper or + pole of a one or more celled galvanic battery, according to the strength required, and the rod is joined with the zinc or – pole, chemical decomposition immediately ensues in the bath, the silver of the cyanide begins to deposit itself on the suspended objects, and the cyanogen, liberated at the plate, dissolves it, re-forming the cyanide of silver. According, then, as the solution is weakened by the loss of the metal going to form the electro-coating, it is strengthened by the cyanide of silver formed at the plate. The thickness of the plate depends on the time of its immersion. The electric current thus acts as the carrier of the metal of the plate to the objects immersed. In this way, silver becomes perfectly plastic in our hands. We can by this means, without mechanical exertion or the craft of the workman, convert a piece of silver of any shape, however irregular, into a uniform plate, which covers, but in no way defaces, objects of the most complicated and delicate forms. When the plated objects are taken from the bath, they appear dull and white; the dulness is first removed by a small circular brush of brass wire driven by a lathe, and the final polish is given by burnishing. The process of electro-gilding is almost identical with that of electro-plating, only the solution must be kept hot. Success in either is attained by proper attention to the strength of the battery, the strength of the solution, the temperature, and the size of the + electrode. In Birmingham, magneto-electric machines are used extensively for furnishing the necessary current in plating.

Electric Light.

138. When the ends of two wires which form the poles of a powerful galvanic battery are made to touch (100), and then are separated for a short distance, the current which passes when the contact is made does not cease with the separation, but forces its way through the intervening air, accompanied with an intense evolution of light and heat. So great is the heat evolved that the most refractory metals are melted by it, and therefore some substance rivalling the metals in conducting power, but much more infusible, must be found to act as the poles, to allow of the continuation of the current in such circumstances. The various forms of carbon are well suited to this purpose; the more compact forms of charcoal answer very well; baked carbon (85) answers better; but the coke that is sublimed inside the retorts in the distillation of gas, both for durability and conducting power, makes by far the best poles. Sir Humphry Davy (1813) first discovered and described the electric light. Fig. 127 represents a simple arrangement for producing it. The carbon-points, P, N, are fixed into hollow brass rods, which are connected with the battery by wires entering at the binding screws *s*, *s*. The rods slide in the heads of the glass pillars A, A, fixed to a stand, so as to admit of the points being placed at different distances. The wires from the battery-poles being properly connected, the points are made to touch, and are then withdrawn

a line or two, when the most dazzling light ensues, rivalling the light of the sun in purity and splendour. Its intensity is such as to prevent the eye from examining the particulars of

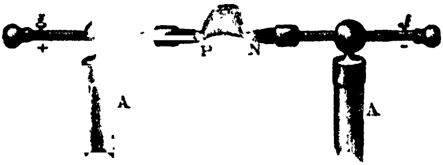


Fig 127

its production. These, however, may be ascertained by projecting with a lens of short focus the images of the points on a screen, when they are seen as shewn in the figure. The light is found to arise chiefly from the intense whiteness of the tips of the carbon rods, and partially from an arch of flame extending from the one to the other. The + pole is the brightest and the hottest, a fact which may be proved by intercepting the current, when the + pole continues to appear red for some time after the − pole has become dark.

During the maintenance of the light, a visible change takes place in the condition of the poles. The + pole experiences a loss of matter; particles of carbon pass from it to the − pole, which they partly reach, and partly are burned by the oxygen of the air on the way. The same takes place, though to a much less extent, with the − pole; so that while the + pole becomes hollowed out or blunt by its losses, the − pole remains pointed by its apparent gains. The wasting away, particularly of the + pole, in a short time renders the distance between the poles too considerable to allow of the passage of the current, and the light is thus suddenly extinguished, until again renewed by contact and removal. The points may be removed with a powerful battery four or five millimetres before the circuit is broken. The transference of matter between the poles is considered to account for the existence of the arch of flame, and the passage through the air of the current, as thereby a conducting medium extends between the poles. The heat of this arch of flame, or *voltaic arc* (Fr. *arc voltaïque*, Ger. *galvanischer Flammenbogen*), as it is called, is the most intense that can be produced. Platinum melts in it like wax in the flame of a candle. Quartz, the sapphire, magnesia, lime, and other substances equally refractory, are forced by it into a state of fusion. The diamond when placed in it becomes white hot, swells up, fuses, and is reduced to a black mass resembling coke. In this condition, it is still hard enough to scratch glass, but possesses almost no consistency, giving way to the pressure of the fingers.

The electric light is caused, not by the combustion of the carbon, but by its being brought into a state of incandescence. The electric light can, in consequence, be produced in a vacuum, and below the surface of water, oils, and other non-conducting liquids. It is thus quite independent of the action of the air, a circumstance which may yet be turned to useful account.

With a battery of some fifty Bunsen's elements, a light is produced of very great brilliancy; but when very great power is to be obtained, as well as brilliancy, twice or thrice that number must be employed. Fifty cells give an electricity of the needful tension to produce the light; and if more be employed, they must add to its strength, and not its tension. Thus, if 150 cells be used, they would be best arranged in three batteries, the + poles of all three being joined to form one + pole, and similarly with the − poles. With a battery of forty or fifty cells, no pointing of the rods is necessary, as this is done by the action of the electricity itself.

The spectrum of the electric light is found to abound in violet rays, and hence it is well adapted to photographic purposes. Fizeau and Foucault found that with a battery of 46 Bunsen cells, a light was obtained which had 34 times the photographic efficacy of the lime-ball light, both being tested by the effect produced on a plate covered with the iodide of silver. The same electric light, when compared in the same way with the sun, was found to stand as 23 to 100.

139. *Electric Lamps.*—Various arrangements have been invented for maintaining the steadiness of the electric light. The aim in all such is to keep the carbon points,

by some mechanical contrivance, within such a distance of each other that the current can pass between them. Foucault, aided by Duboscq, was the first (1849) who constructed an electric lamp of this description. In it, by aid partly of an electro-magnet, and partly of clock-work, the two points are made to travel towards each other at rates corresponding to those of their consumption, the + pole in this way travelling faster than the −. A detent is fixed to the keeper of the electro-magnet, which locks the clock-work when the keeper is brought up to the magnet, and withdraws it when it is away from it. The keeper is acted upon by a counter-spring, which draws it away from the magnet when the current does not circulate, or when it is too weak to act effectively. Thus, when the points waste away and separate from each other, the current becomes weaker, and when it gets so weak as to impair the splendour of the light, it is so arranged that the spring draws away the keeper, and thereby liberates the clock-work. The points are now made to approach until the current, by the nearing of the points, acquires sufficient strength to draw the keeper to it and insert the detent. There is thus a constant locking and unlocking of the clock-work, and the points are kept at the distance fitted to produce the most brilliant light. In the simpler form of lamps, provision is not made to keep the points, as in Duboscq's, at the same absolute position, but it is only sought to keep their relative distance the same. The consumption of the − pole is so slow that it occasions little inconvenience to keep it fixed, and to confine the motion of approach to the + pole. An ingenious and simple lamp of this kind is made by Mr Hart of Edinburgh. The weight of the rod in which the carbon is fixed supplies the place of the clock-work in Duboscq's lamp, and an electro-magnet lets it descend or locks it, according as the carbons are consumed. A lamp of either kind gives a brilliant illumination to the magic lantern or solar microscope.

140. The attempts which have been made to substitute the electric light for coal-gas in lighting up streets and public places, have hitherto proved unsuccessful. One element of imperfect success is to be found in the uncertainty of the

light and the care attending its use. By contrivances similar to those described above, the light may be continued for hours, but even then it is by no means perfectly steady, and the apparatus cannot be safely left without an attendant. Another arises from the striking and unpleasant contrast of light and shadow that accompanies it, rendering, as it were, the surrounding gloom as manifest as the brightness of the light. It has, however, been used with excellent effect where a limited space had to be lit up for a few nights, such as in the construction of bridges across rivers and the like. It has also been applied with success to light-house illumination. The light-house at Dungeness has been lit up with it since 1862, and that at La Heve, near Havre, since 1863. It has been found from these that the power of the electric light to penetrate fogs is immensely superior to that of the usual oil light. At both light-houses the current is got from magneto-electric machines, driven by steam-engines. The machine at Dungeness was designed by Professor Holmes; it sends, by means of a commutator, the current in a uniform direction to the carbon points. The intensity of this light is said to be as 7 to 6 when compared with that of sunlight. At La Heve, the alternate currents are sent to the points without the intervention of a commutator, which is attended with this advantage, that both carbons are consumed at the same rate. The carbons are ten inches in length, and last five hours. They are kept one millimetre apart. The expense of maintaining the light, including coals, interest on capital expended, carbons, salaries, &c., is about two shillings per hour at La Heve. The galvanic battery has hitherto been found too troublesome a source of electricity for light-houses. Duchemin has lately, however, constructed a *marine battery*, where a constant current is maintained by the simple action of sea water on zinc, which may yet prove important for such purposes. A cylinder of carbon and a plate of zinc are attached to a float of cork, and moored by conducting wires to the shore. As the supply of the exciting fluid is inexhaustible, no care is needed to keep the pair in steady working order. It has yet only been tried on a small scale.

Exploding Gunpowder at a Distance.

141. The application of the galvanic current to exploding gunpowder at a distance depends on the power it has to ignite thin wires of comparatively bad conducting metals, such as steel and platinum (100). The current must be transmitted to the point where the explosion is to take place by good conducting wires, and the thin wire is made to connect the two ends of these wires in the gunpowder. A red-heat is thus only developed at the spot where it is required. The circuit is not completed until all arrangements for the blasting are ready, and all persons connected with the preparations are at a safe distance from it. Roberts (1838) devised a method of conducting galvanic blasting which has since become universal. It is shewn in fig. 128. A tin tube, 3 inches long and ¾ of an inch wide, is filled with gunpowder, and stopped with a cork at each end. Through one of the corks, two copper wires are inserted, ending in the cartridge in something like a pair of horns. The wires are insulated from each other by woollen yarn. They are continued without the cartridge for about 10 feet, when they part company so as to allow the battery wires to be attached to them. The ends of the horns within the cartridge are connected by a thin steel wire, ½ an inch in length, wound round and soldered to each of them. At the ends there is of course no insulating matter; indeed they must be filed or cleaned so as to make the connection with them and the thin wire complete. When a hole is bored for blasting, say 6 or 7 feet long and 2 inches wide, the charge of powder and the cartridge are inserted so that the cartridge lies in the middle of the charge, and the rest of the bore is filled with straw and sand in the usual way. The 10-foot wires project beyond the hole, and the battery-wires can be conveniently attached to them. When all is ready, the circuit is completed, and the explosion immediately follows. The

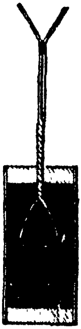


Fig. 128.

steel wire is burnt away by the current, but the long copper wires are uninjured, and ready to be fitted up as before. Such cartridges are generally kept ready for use in mining establishments. In long circuits the function of the return wire may be performed by the earth, as in the electric telegraph.

When several charges have to be fired at once, the whole are generally included in one circuit. As there is always some difference in the steel wires, or in the way they are fitted, it not unfrequently happens that one cartridge is fired before the others. The circuit is thus broken, and the others are left unfired. With this arrangement, there is no certainty of a simultaneous discharge. In such cases, the galvanic current must be abandoned, and recourse must be had to the electricity of the induction coil. If the ends of the wires within the cartridge be brought so near that the induced current can leap over the distance between them, no steel wire is needed, the inductive spark itself can effect the ignition. After explosion, the distance of the ends remains the same and the sparks continue. If, then, there be several charges to be fired in the same circuit, the firing of one does not stop the current, which continues even after all have been fired. The induction spark does not, however, kindle gunpowder with certainty, so that between the ends some material must be placed more easily ignited than gunpowder—such as white gunpowder, gun-cotton, &c. When the number of simultaneous explosions is great (five or six), some very readily exploded substance, such as fulminating mercury, must be placed in the path of the spark discharge.

Abel's fuses, lately introduced, are all that can be wished in the way of certainty and simplicity. Abel does not use a thin platinum wire between the two circuit terminations, but he uses what is in effect the same—a mixture that conducts, but conducts with difficulty. His fuses are primed with a mixture of chlorate of potassium, subphosphide of copper, and subsulphide of copper. The conducting ingredient is the subsulphide of copper, which must be added in such a proportion as to render the whole difficultly conducting. When the current passes through the mixture, it develops sufficient heat to explode it, and thereby the charge of gunpowder. Abel's fuses are chiefly intended for the electricity of the magneto-electric machine or of the induction coil, although the ingredients may be so compounded as to serve also for that of the voltaic battery. A very small machine is sufficient for the purpose. The little pocket machines employed for medical purposes fire readily one of these fuses. They are very small, some of them about half an inch in length, and half the thickness of an ordinary pencil

Electric Clocks.

142. Electric clocks may be divided into two classes—those in which the impulse is given to the pendulum directly by electric power, and those in which it is given by a weight or spring alternately liberated and restrained by electricity. Of the first kind, that invented by Bain (1840) is best known. In the ordinary clock, it is the clock that moves the pendulum; in Bain's clock, it is the pendulum that moves the clock. As the construction of the pendulum is the only part of it connected with electricity, we shall confine our notice to a general description of the pendulum action. The lower part of the pendulum arrangement is shewn in fig. 129. The bob, B, consists of a bobbin of insulated copper wire, and is hollow in the centre; the wires *w*, *w* from both ends run along each side of the pendulum rod R (the lower part of which alone is seen), and are in metallic connection respectively with the two springs from which the pendulum hangs. Two magnets or bundles of magnetic rods, NS, N′S′, are fixed at either side of the bob, and are of such dimensions that the hollow bob in its oscillation can

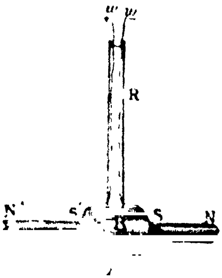


Fig. 129.

pass a certain way over each without touching. The magnets have their like poles turned towards each other. The two springs of the pendulum rod are in connection with the two poles of a galvanic battery. In the connection between one of these springs and the battery, there is a break (not shewn in the fig.), worked by the pendulum rod. When the pendulum is made to move, say towards the right, it shifts a slider, so as to complete the connection between the poles of the battery. The current thereupon descends one of the wires of the pendulum, passes through the coil of wire forming the bob, and ascends by the other. In so doing, it converts the bob into a temporary magnet (113), the south pole towards the right, and the north pole towards the left. In this way, the south pole of the bob is repelled by the south pole S of the right-hand magnet; and its north pole is attracted by the south pole S′ of the left-hand magnet, so that from this double repulsion and attraction both acting in the same direction, the bob receives an impulse towards the left. Partly, therefore, from this impulse, and partly from its own weight, the pendulum describes its left oscillation; and when it reaches the end of it, it moves the slider so as to cut off the battery current, and then returns towards the right, under the action simply of its own weight. On reaching the extreme right, as before, it receives a fresh impulse; and thus, under the electric force exerted during its left oscillation, the motion of the pendulum is maintained. So long as the electricity is supplied, the pendulum will continue to move. The current required is exceedingly weak, and Bain considered that it could be sufficiently excited by a plate of copper and a plate of zinc sunk into the ground, and acted upon by the moisture usually found there. This *earth-battery*, as he called it, was expected to act steadily for years; but the result proved far otherwise, for the soil not unfrequently dried up, leaving no trace of electrical action. The imperfection of the battery has led to a strong prejudice against these clocks—stronger, certainly, than they merit. It has been found, however, by those who have employed them for astronomical purposes, that little dependence could be placed on them, and that the proper conditions of pendulum motion were, from the unsteady supply of electricity, interfered with; hence the opinion has been generally accepted, that a pendulum moved immediately by electricity, does not keep very accurate time; and the efforts that have of late been made in electric clock-making, have aimed at rendering the pendulum independent of the irregularities of the motive agent.

A very important application of Bain's pendulum has been made by Mr Jones of Chester. Shortly after the invention of Bain's clock, Professor Wheatstone suggested that any number of such clocks could be made to move simultaneously by the same current of electricity. Mr Jones has turned this idea to account in the following way. A standard clock of the usual construction is made, by regulating the flow of a galvanic current, to control the action of any number of copying clocks, likewise of ordinary construction. The pendulum of the standard clock itself, in no way under electric control, on passing towards the right, touches a spring, placed at the side, thereby completing the battery connection, and a current is transmitted to the copying clocks in a certain direction. On passing to the left side, the same takes place, but the current this time is sent through the circuit in the opposite direction. The pendulums of the copying-clocks are made on Bain's principle, but have, of course, no break to move, as the primary pendulum performs that function. Let us suppose, at first, that all the pendulums are at rest; in this case, no current is transmitted. Let the standard pendulum now be moved to the right, the right spring is touched, and a current at the same instant circulates through the bobs of the copying pendulums, and they thereby receive a simultaneous impulse towards the left. All the pendulums move then to the left; and on reaching the extremity of this oscillation, the standard pendulum touches the left spring, and the secondary pendulums are now impelled to the right. The motion of each secondary pendulum soon increases, until it reaches its proper extent. The pendulums once set a-going, are, however, not intrusted solely to the stimulus of the electricity, but are moved by their own weights, as in ordinary clocks, so that if the electricity ceased to be sent to them, they would go on without it. It might be supposed that a confusion of the two forces, electricity and gravity, would ensue; such, however, is not the case. While the motion of the clock is intrusted to its own weight, the pendulum submits docilely to the controlling action of the electricity; and thus a copying clock of little value may be invested with all the perfection of the most costly observatory clock. The success of Jones's pendulum has been severely tested in the arrangement employed by Professor Smythe for firing the one o'clock time-gun at Edinburgh. A clock in the castle of Edinburgh is made to liberate the trigger of the gun exactly at one o'clock. This clock is regulated on Jones's principle, by a clock at the Observatory on the Calton Hill, nearly a mile distant. The Observatory clock, by means of electricity, sets off a time-ball on Nelson's Monument, about 100 yards off, at the same instant. The fall of the ball, and the flash of the gun, though occasioned each by its own clock, are perfectly simultaneous.

In the second class of electric clocks, the electricity is not charged immediately with the maintaining of the pendulum motion, but draws up the weight, or liberates the spring which discharges that function. This is the same principle as holds in what is known in horology as the 'remontoir' escapement. Mr Shepherd of London was the first to introduce this principle into electric clock-making, and one of his clocks on a large scale was exhibited at the Great Exhibition of 1851.

Electro-magnetic Machines.

143. These take advantage of the facility with which the poles of an electro-magnet may be reversed, by which attractions and repulsions may be so arranged with another magnet as to produce a constant rotation. The forms in which they occur are exceedingly various, but the description of the apparatus in fig. 130 will suffice to illustrate their principle of working. NS is a fixed permanent magnet (it could be equally well an electro-magnet); the electro-magnet, *ns*, is fixed to the axis, *ee*, and the ends of the coil are soldered to the ring *c*, encircling a projection on the axis. The ring has two slits in it, dividing

it into two halves, and filled with a non-conducting material, so that the halves are insulated from each other. Pressing on this broken ring, on opposite sides, are two springs, *a* and *b*, which proceed from the two binding-screws into which the wires, + and −, from the battery are fixed. In the position

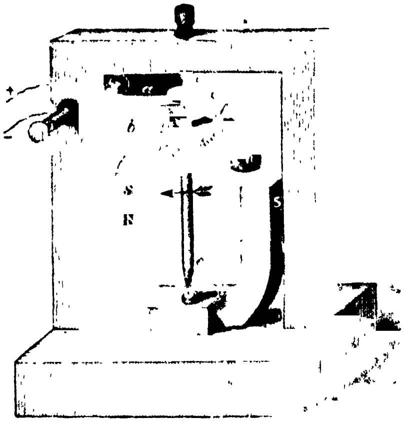


Fig. 13[illegible].

shewn in the figure, the current is supposed to pass along *a*, to the half of the ring in connection with the end *f*, of the coil, to go through the coil, to pass by *g* to the other half of the ring, and to pass along *b*, in its return to the battery. The magnetism induced by the current in the electro-magnet, makes *s* a south and *n* a north pole, by virtue of which N attracts *s*, and S attracts *n*. By this double attraction, *ns* is brought into a line with NS, where it would remain, did not just then the springs pass to the other halves of the ring, and reverse the current, making *s* a north, and *n* a south pole. Repulsion between the like poles instantly ensues, and *ns* is driven onwards through a quarter revolution, and then attraction as before between unlike poles takes it through another quarter, to place it once more axially. A perpetual rotation is in this way kept up. The manner in which a constant rotary motion may be obtained by electro-magnetism being understood, it is easy to conceive how it may be adapted to the discharge of regular work. Powerful machines of this kind have been made with a view to supplant the steam-engine; but such attempts, both in respect of economy and constancy, have proved utter failures. It has been found that zinc cannot compete with coal as a source of mechanical action.

Jacobi was the first (1834) to construct such machines. In 1838 he constructed a machine of ¾ of a horse power, by means of which he propelled a small boat on the Neva.

Electric Telegraph.

144. The electric telegraph, like every other telegraph, aims at producing intelligible signals at a distance. The etymology of the word (*tele*, far off, and *grapho*, I write) implies that it is an instrument for writing at a distance; but it has come to signify any means of conveying intelligence other than by voice or writing. The idea of speed is also implied—telegraphs being seldom, if ever, employed where they cannot transmit intelligence at a much quicker rate than can be done by the ordinary means of transit. There are three agents, which, from the rapidity of their propagation, are employed for telegraphing—sound, light, and electricity. Sounds, such as those of bells, guns, &c., form a convenient means of sending a single message through short distances. Light and electricity immeasurably exceed sound as ready, rapid, and certain means of telegraphing through long distances. Light, though an extremely rapid, is by no means a docile agent. It proceeds in straight lines, and will not bend round the ball of the earth, or inequalities on its surface. The semaphore, which was an ocular telegraph, and the only good one before the electric telegraph, illustrated this. Towers had to be erected in prominent positions, within sight of each other, and the signals, which were made by arms on the top of them,

had to be retransmitted at every station. A large and well-trained staff was necessary to observe and transmit, and withal the work was slowly done. In foggy weather, moreover, the semaphore was useless. Electricity, which rivals light in speed, is most docile and trustworthy as a telegraphic agent. It silently wends its way in all weathers, over plain and mountain, across sea and land, and delivers its message familiarly in the office or parlour almost at the precise instant it was sent.

The various forms of electric telegraphs in general use are electro-magnetic. The signals are given by the deflection of a needle to the right or left, or by mechanism connected with the armature of an electro-magnet, which sways to and fro under the action of the magnet and a counter spring, or between two opposite electro-magnets. Electro-chemical telegraphs have also been designed, but they have never come into permanent use. Electric telegraphs of all classes are of two kinds—those which merely give passing signals to the observer or listener, and those which permanently record their signals; the former may be called signalling, the latter recording telegraphs. The number of inventions connected with the electric telegraph is almost endless, and would engross a long series of volumes for their description. We shall here content ourselves with giving a mere outline of the working of the telegraph at present existing on most lines. The forms most in use everywhere at present are Morse's Telegraph and Cooke and Wheatstone's Needle Telegraph. For private use, some form of the magneto-electric dial telegraph is employed. In point of simplicity and certainty, Morse's system cannot be exceeded, and even as regards speed it stands equal, or nearly so, to the most rapid recorders. We shall therefore give an account of the general arrangements of a telegraph chiefly on Morse's system.

145. *Morse's Recording Instrument*, or as it is shortly called, the 'Morse' or 'Register,' is shewn in fig. 131. L is the line-wire, and E the earth-wire, conveying the current from the distant station. The current thus sent traverses the coils of the electro-magnet, MM′, the armature, A, of which is in consequence drawn down. A is attached to the lever *ll′*,

moving round the axis *k*. By the attraction of A, the end *l′* is lowered, and brought against the stud *n*. The armature must not touch the soft iron of the electro-magnet on being drawn down, for if it did it would stick, and would not be instantly released when the current ceases (114). When

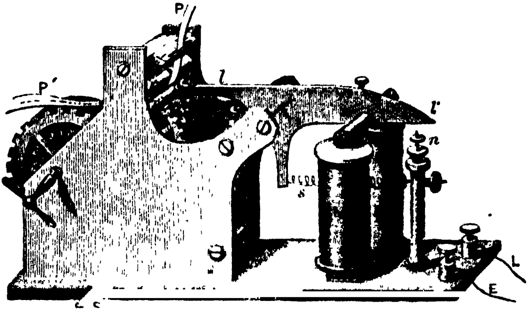


Fig. 131

the end *l′* is lowered, the end *l* is raised; *ll′*, at its inner end, carries a steel point or style, *p*, which by the upward motion is brought against a strip of paper, PP′, carried towards P′ by the rollers *rr′*, set in motion by clock-work, C, quite independently of electricity. The clock-work is liberated or stopped by the switch S. The paper is supplied from a large roll or bobbin, above the instrument, which turns round as the rollers demand. So long as the style is elevated, the paper strip is made by the clock-work to rub against it. A line is thus embossed on its upper surface. To facilitate the doing of this, there is a groove in the upper roller, opposite the style. When the current from the distant station ceases, the lever *ll* is pulled back to its original position by the spring *s*, and the style falls away from the paper. To prevent it falling too far, another stud, *m*, lies on the other side of the axis. When the circuit is again closed, the style once more marks the paper, and thus the lever keeps oscillating under the opposing actions of the magnetism developed by the transmitted current, and the elasticity of the spring *s*. The time that the style remains elevated, determines the kind of mark on the paper. If it is nearly momentary, a dot is imprinted; for a longer time, a dash. We have thus the combinations of an alphabet in the combination of dots and dashes. The following is the usual Morse Alphabet:

A	. —	J	. -- —	S	. . .
B	— . . .	K	— . —	T	—
C	- . — .	L	. - - . .	U	. . —
D	. .	M		V	. . . —
E	.	N	— .	W	. — —
F	. . — .	O	-- — - -	X	- - . . . -
G	- — .	P	. - - — .	Y	-- . — —
H	. . . .	Q	- — . —	Z	-- - - . .
I	. .	R	. — .		

Thus A is a dot and a dash; B, a dash and three dots, &c. The alphabet is so arranged that those letters occurring most frequently are more easily signalled; thus, E is one dot; T, one dash. An expert telegrapher can transmit from thirty to forty words a minute by this instrument on a land-line of between 200 and 300 miles. Several modifications of Morse's telegraph have been made, the principal of which is to substitute ink marking for embossing. The beautiful instruments of the Siemens and Halske are of this kind.

A clerk that has been well accustomed to a Morse telegraph, in transcribing, seldom looks to the paper. The mere clicking of the lever becomes a language perfectly intelligible to him. He need therefore only look to the record when he may have heard indistinctly. Sir Charles Bright does away with the recording instrument altogether, and substitutes two bells, one muffled, the other clear, sounded by a hammer oscillating between them. The bells speak a telegraphic language as quick as the clerk can write. Recording instruments are generally considered preferable to instruments which merely signal, as they fix any fault of transmission or copying on the party at fault. Acoustic signalling, again, is preferable to ocular signalling, as a person can hear and write much more easily than see and write.

146. *Transmitting Key.*—Let us now transfer our attention

to the distant station, to see how the current is transmitted from it. This is done by the transmitting key shewn in fig. 132. A brass lever, *ll*, moves round the axis A. On opposite sides of the axis two nipples of platinum, *m*, *n*, are soldered to its lower sides. The nipple *m* is called the hammer. Below *n* is the stop anvil, *b*, tipped with platinum, which is in connection with the earth-wire E. Below the hammer, *m*, lies the anvil *a*, the nipple of which is likewise of platinum; *a* is connected by the wire C with one of the poles of the sending battery, generally the copper pole. When the lever is left to itself, *n* and *b* are in contact under the force of the spring *s*. When the hand presses on the ebonite (insulating) handle H, contact is broken at *n* and *b*, and established at *m* and *a*. Three wires are in connection with the key, E and C just named, and L the line-wire from the distant station connected with the axis pillar, and therefore with the lever. When the key is in the receiving position, that shewn in the figure, the current from the sending station takes the route L, A, *l*, *n*, *b*, E, the Morse, then to earth. When H is pressed down, the key is in the sending position, and transmits the battery current by C, *a*, *m*, A, L, to the distant station. The play of the anvil and hammer need not be more than $\frac{1}{10}$th of an inch. This is more than sufficient (101) for completely breaking the current, and it allows of speedy manipulation.

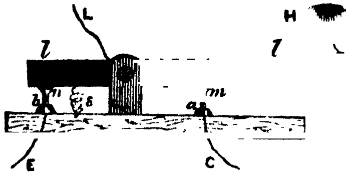
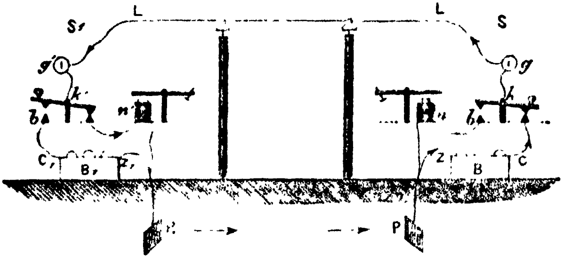


Fig. 132.

147. *The Battery.*—The batteries employed are in this country almost universally Daniell's. Constancy and certainty of action is what is most wanted in the battery, and this Daniell's battery yields. In Germany, Bunsen's battery is also used, charged with diluted sulphuric acid, the carbon being immersed in a mixture of 1 of acid to 10 of water, and the zinc in one of 1 to 20. When batteries have to be moved about much, sand is put in to keep the liquid

from spilling. The number of cells employed varies with the distance, the insulation of the line, and the delicacy of the instruments. The register, as afterwards mentioned, is seldom worked directly by the transmitted current, but by relay. To work a relay with good insulation, 60 Daniell's cells will suffice for a distance of 300 miles. For less distances, less of course will suffice. For short circuits, where the resistance is small and current strong, small cells soon exhaust themselves; large cells therefore must be used to maintain the supply. Magneto-electricity is also employed as a source of the current. This answers well on short circuits, or for private telegraphs, but experience has proved that the galvanic battery is by far the most advantageous source of electricity for extensive telegraphic work.

148. *How Two Stations are connected together.*—The manner in which two stations are 'joined up' on Morse's system is shewn in fig. 133. B and B_1 are the batteries at the stations



S, S_1; *k*, *k′* are the transmitting keys; *n*, *n′*, the registers; *g*, *g′*, the galvanometers; LL the line-wire insulated on posts; P, P_1, the earth-plates. When the key *k*, at the station S, which is here represented as the sending station, is depressed, the current from the battery B takes the following course. From the copper pole C, of the battery B, it goes to the anvil of *k*, passes through *k* to the galvanometer *g*, which having traversed, it goes into the line LL to the receiving station S_1, traverses the galvanometer, the key *k′*, the coils of the register *n′*;

thence it goes 'to earth' at the plate P_1, returns by the ground to P at the sending station, and thus finally reaches the zinc pole Z of the battery B. At station S, *b* and *n* are out of circuit; and at S_1, *b′* and battery B_1 are out of circuit; *n* is thrown out of circuit, because its coil offers a resistance equal to several miles of the line-wire, and it is requisite to keep down the resistance to the minimum. If it were in circuit, both registers could print simultaneously, but that is not necessary, one record at the receiving station being enough. The sender would thus have no idea as to whether his message had told or not, did not the motions of the needle of the galvanometer, *g*, reveal the currents put in circuit. The galvanometer also shews the presence of earth-currents on the line. If *k* were left to itself, and *k′* depressed, the station S_1 would then be the sending and S the receiving station, and the connections would be exactly as shewn in the figure, only at opposite stations.

Suppose the clerk at S wishes to telegraph to S_1, he depresses the key *k* several times, so as to send a series of dots and dashes giving the name of the station. The attention of S_1 is first arrested by the clicking of the armature of the Morse. He thereupon turns the switch S (fig. 131), and sets the clock-work in motion, and sends back to S that he is ready, and the printing thereupon begins. When both keys are depressed, the whole circuit is broken, so that when both sender and receiver have their hands on their respective keys no message can be sent. One might fancy that confusion would arise from cross messages, but clerks soon get over this inconvenience, and communicate back and forward with perfect facility. There is a code of working signals to indicate the kind of message, 'repeat,' 'understand,' &c., besides numerous recognised contractions. To arrest the attention of attendants, the current is sometimes made to ring an alarum bell.

149. *The Line.*—Telegraphic stations must be united by one insulated wire, either carried over land or under the sea. The insulation of land-lines is insured by attaching the wires to insulators fixed on posts some 20 feet high. The posts are placed at distances corresponding to the number of wires they

have to carry. A distance of 80 yards is the ordinary distance for posts sustaining several wires, and 150 yards for those only supporting one. Insulators are of all shapes. Porcelain, though a better conductor than glass, is not so apt to attract moisture, and is the substance generally employed for them. The insulator known as Andrew's Insulator, and used by the United Kingdom Company, which is shown in section fig. 134, is said to be very effectual. A bolt of iron, I, fixed to the cross-beam *w*, of the telegraph pole, is cemented into the ebonite cup or bell *ee*, which in turn is cemented into the porcelain bell *pp*. The porcelain bell acts as an umbrella to keep the wood to which it is fixed dry and insulating; that failing, the inside of the two cups is likely to remain dry and maintain insulation. The line-wire is kept fixed by binding wire into the groove *a*. The electricity has thus to travel over the outside and inside of both cups before it reaches the iron bolt, which is also coated with ebonite. Such insulators as the one described cannot be used in railway tunnels, as they get coated over inside and out with engine smoke, which, being conducting, quite impairs their efficiency. The leakage in a long line, notwithstanding the best insulation, is considerable. The loss at each post is insignificant, but when hundreds or thousands are taken into account it becomes decided, so that merely a fraction of the total current that sets out reaches the earth at the distant station. In rainy, and more especially in misty weather, the insulation suffers much.

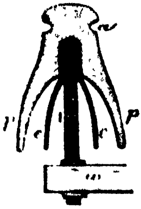


Fig. 134.

The wire most employed for land lines is No. 8 galvanised iron wire. The Electric Telegraph Company are beginning to use No. 4 wire on some of their long trunk lines.

150. *A Submarine Line* is made by a cable. The core of the cable consists of one wire, or a strand of several wires of copper, as pure as can be got in the market. One solid wire is preferable to a strand of the same diameter in point of conducting power; but a strand is surer; for when one wire is broken at any point, the others still remain to conduct the current; there is no 'breach of continuity.' When the one

solid wire gets broken, which not unfrequently occurs without being visible outside, the cable becomes useless. The strand of wire is generally laid up in Chatterton's compound, consisting of gutta-percha and resinous substances. The interstices between the wires are thus filled up, and this makes the cable solid throughout. It not unfrequently happens, when this precaution is not taken, that water, under the great pressure of ocean depths, becomes injected into them. The strand thus laid up, is now included in one or more coatings of gutta-percha, which acts as the insulating protection for the wire. Chatterton's compound is generally put between the layers of gutta-percha. The whole is finally included in a sheathing of iron wire, laid on spirally, to give the cable sufficient strength to withstand the strain of paying out, or that to which it may be subjected by the inequalities of the ocean bed. Between the iron sheathing and the gutta-percha, a layer of tarred yarn is put, which acts as a padding between the two, and improves the insulation of the cable. Not unfrequently the iron wire of the sheathing is also protected from corrosion by tarred hemp. Fig. 135 (full size) shews the construction of the Malta and Alexandria cable. The different layers are so far peeled off to shew the construction. C is a strand of seven copper wires, laid in Chatterton's compound; G, three layers of gutta-percha, with Chatterton's compound between each; H, tarred yarn; and I, the eighteen wires constituting the sheathing. The diameter out in the sea is 0·85 of an inch. Near the shore, the sheathing is made much stronger, to meet the danger of accident from the dragging of anchors, currents, &c. For the same reason, cables for shallow water are made thick and strong.

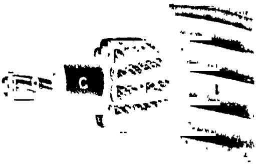


Fig 135.

Considerable dispute has arisen as to the best material for insulating marine cables. India-rubber and gutta-percha are the two rival substances. It may be said in favour of gutta-percha that not one yard of it, when laid, has decayed, and that under ocean pressures, as proved by the last Atlantic cables, its insulating power decidedly improves. In favour of well masticated india-rubber, it is urged that cables, alike in other respects, will, when coated with it instead of gutta-percha, be capable of sending twice the number of words per minute, the specific inductive capacity being so much greater for the latter than for the former substance. On the other hand, india-rubber is not so trustworthy in point of durability, some specimens of it having become treacly after immersion for some time in the sea.

151. *The Earth.*—Two wires are not necessary to connect two telegraphic stations, as might be supposed. One wire is quite sufficient, provided its terminations be formed by large plates sunk in the ground, or something equivalent. The plates are generally of copper, and should not offer a surface less than twenty square feet, and they must be buried so deep that the earth about them never gets dry. The gas and water pipes in a town make an excellent 'earth' (earth connection). The great object in an 'earth' is to put the whole ground in the neighbourhood in connection with the battery pole or line wire, and much the same precautions must be taken in making an earth for a telegraph as for a lightning-conductor (55). If the earth is not good, the current, instead of taking the ground as a passage to the distant station, runs into other wires connected with the plate and leading to where the 'earth' is good. When the 'earths' are good, the current passes through the earth between the two stations, no matter what be the nature of the country it has to pass, plain or mountain, sea or land. The earth resistance to the current, compared with that of a long line, is next to nothing. The earth not only serves the purpose of a second wire, but of one so thick that its resistance may be left out of account, and thus halves the resistance of the whole circuit. It is a question whether the current actually travels between the two stations, or whether an equal amount of opposite electricity becomes simultaneously lost at each. This question cannot be decided, as the electric conditions in either case are identical. In conducting power for equal dimensions, the earth stands much inferior to the wire, but then its thickness, so to speak, is indefinitely greater, and

hence its superior conducting power on the whole. One good 'earth' serves for all the circuits of a telegraphic station.

152. *Return Current—Inductive Embarrassment.*—When the line-wire at a distant station is 'cut' (insulated or disconnected with the ground), and is placed in connection with one of the poles of a battery, the other pole of which is to earth, at the instant in which the connection is made, a current flows into the wire, and if the insulation of the line be perfect, almost instantly ceases. The needle of the galvanometer makes a sudden deflection, and then returns to its position of rest. If now, at one turn of a commutator, the battery connection be cut off, and the line be put to earth, the needle deflects momentarily in the opposite way, and the charge given to the wire returns and goes to earth. This flowing back again of the charge is called the *return current.* In land-lines the return current is very slight, in submarine cables it is very marked. The return current shews that a telegraphic line may be charged statically, just like the insulated balls, cylinders, &c., illustrating frictional electricity. A line of telegraph may be looked upon as a Leyden jar, the wire as the inner coating, the air or gutta-percha as the glass or dielectric, and the earth or sea as the outer coating. A coil of submarine cable, immersed in a trough of water when the core is insulated, may be charged and discharged exactly as a Leyden jar, the water being the outer coating. The return current is most marked in long lines. In such it is not necessary to 'cut' the wire, the great resistance of the long wire being equivalent to partial insulation; the return current being, however, much smaller in extent.

The statical charge, of which a line of telegraph is thus capable, shews that the electric force not only tends to propagate itself longitudinally, but laterally (34, 63). The effect of lateral induction is to retard the time of delivery of a signal, and to prolong it, so that although it is a momentary signal at starting, it becomes a prolonged signal at its destination. Wheatstone's calculation (50) gives a velocity of 288,000 miles per second for electric discharge. If signals were propagated at this rate, the time elapsing between the sending and delivering of a current, even on a line extending over one half the circumference of the globe, would be inappreciable. But in aerial lines of land telegraphs, even only a few hundred miles in length, there is evidence that electricity does not propagate itself at anything like that speed, and in submarine cables the velocity scarcely reaches thousands of miles per second. The mere slowing of the message would not matter so much, provided the signals, when they reached their destination, were told out as they were sent. But they are not. Each signal at the receiving station takes a longer time to leave the line than it did to enter it. Hence, in a very long land-line, or in a cable, if the sender transmitted at the same rate as he does in short circuits, the signals would run into each other at the receiving station, and be undistinguishable. Time must be given to allow each signal to ooze out of the cable before another is sent. The effects of lateral induction on the transmission of telegraphic currents constitute what is termed *inductive embarrassment.*

According to Sir William Thomson, the maximum speed attainable on an aerial land-line of 2000 nautical* miles in length, and consisting of an iron wire one-fourth of an inch in diameter, would be 20 words per minute. The same authority has established that *the retardation increases with the square of the length of the line.* Accordingly, on a line 1000 miles in length, the number of words would be 80; on one 500 miles, 320, and so on. Direct lines are not worked for distances greater than 1000 miles, and very seldom even for the half of that distance. The maximum speed of telegraphing on short circuits has been 50 words; so that on a line 1000 miles in length and one-fourth of an inch thick, there is still a wide margin before the lateral induction would interfere. Most land-lines, however, are not more than one-eighth of an inch thick, and in them the embarrassment would be felt nearly four times as much as in the line just mentioned. On a line 1000 miles in extent of No. 8 wire, it would be advisable to break the circuit half way, and resend at the mid-station by translation. The whole would thus be worked as two circuits of 500 miles, and the speed of signalling could be four times increased. The maximum speed of signalling through the 2000 miles of the Atlantic telegraph of 1858 was two and a half words a minute. The copper core had a conducting power somewhat higher than a No. 4 iron wire. According to the law of squares, if the cable had been 1000 miles, the rate of signalling might have been increased to 10 words; if 500 miles, 40 words; and so on. If the ratio of the thickness of the core to that of the insulating coating be kept the same, the number of words that can be sent varies as the amount of material employed, or as the square of the diameter of the cable. Thus, if a cable be of the same make and of equal length as another, but twice as thick, four times as many words may be sent by it. The thickening of the core alone is not all gain in the way of lessening embarrassment, for while the conducting power of the core increases with its section, the lateral induction increases with its circumference.

Numerous explanations have been given of inductive embarrassment. We may suppose the charge at starting to have two inductive channels to reach the ground, one through the core to the further end of the cable, and the other through the gutta-percha. Electricity, when it has two channels, acts through each in the proportion of the facility offered it (34, 63). If the gutta-percha were thick and the core short, the facility offered by the latter would be indefinitely greater than that offered by the former. There would be then no lateral induction, for the electricity would keep to the core. But when, as in long cables, it has some hundreds of miles of core and a quarter of an inch of gutta-percha to work through, the rival channels stand more nearly on a par. At each point the part of the electricity sent into the cable acts inductively through the gutta-percha, and the rest acts in the line of the core. This last is subject to this diversion as it moves along; hence, if the cable be long, the whole is for the instant absorbed in charging the cable statically, and possibly only a part at a time. Such being the case, the further progress of discharge is effected not immediately by the force of the transmitting battery, but by the polarity induced by it in the particles of the dielectric gutta-percha. The effect is somewhat the same as would be experienced in sending a charge of water through a pipe filled with the same, whose sides, though water-tight, were elastic. If the pipe be long and narrow, and the friction of the water against the sides consequently great, on the charge being injected, the pipe on the sending side yields, and the further transmission of the charge is effected by the elastic force of the sides. The charge travels as a wave to the other end, and its delivery is thereby retarded and modified. This temporary yielding resembles the inductive diversion of the charge to the gutta-percha.

In aerial lines the lateral channel, the air, which is some twenty feet thick between the wire and the ground, offers much less facility for inductive action than in gutta-percha cables. The lateral induction is consequently very much less. In insulated subterranean lines it is nearly as much as in submarine cables. They are consequently never used except for short distances, where they are unavoidable.

There is as yet no way of obviating lateral induction in telegraphic cables, except a thick core and a thick layer of insulating material. This is tantamount to saying there is no cure at all; for in very long lines, where it is most felt, a thick cable cannot, from mechanical difficulties, be laid. There are several ways, however, of diminishing it. A material, such as india-rubber, whose specific inductive capacity is low, lessens the evil considerably. The tarred hemp used in cables also reduces the lateral induction. Some have suggested the use of a double wire in the cable, the second wire supplying the place of the earth. This has, however, been found to aggravate instead of lessen the evil. The use of electricity of high tension, such as that of induction coils, has also been tried. That such passes with greater despatch may be open to doubt, and that it is dangerous in causing the charge to puncture the gutta-percha, and thereby destroy the cable, is highly probable. A transmitting key is used in working the Atlantic cable, which has a double action. It first places the cable in connection with one of the poles of the battery, and then with the ground. The first connection charges the cable, the second allows discharge to take place at both ends of it. See also Appendix, 'Atlantic Telegraph.'

The insulation of submarine cables is almost perfect, so that inductive embarrassment must not be confounded with leakage. The gutta-percha, though a conductor acting excessively slowly, leads away, in the time that one signal lasts, next to nothing of the charge. Its action is inductive, not conductive (30, 33).

153. *Earth Currents.*—These are very unwelcome visitors in telegraphic offices. They get into the circuit no one knows how. They flow sometimes in one direction, sometimes in another, change rapidly, and are frequently so strong as to render the line for the time quite useless. They seem to be formed as often in the wire as in the earth. They occur simultaneously with magnetic storms (20). The famous magnetic storm that raged on August 2, 1865, at the same time that the Atlantic cable ceased to act, was accompanied by earth currents so strong that the astronomer-royal considered it impossible, even if the cable had been perfect, to have signalled through it. The only remedy for earth currents is to do away with the earth circuit, and put two wires to the same place in one circuit. Although the earth current runs equally strong in both, the two wires bring it to opposite ends of the instruments at the stations, and its effect is thereby neutralised. This, of course, can only be done where two wires exist. Little or nothing is as yet known of the laws regulating such currents.

154. *Relay* (Ger. *Uebertrager*).—Hitherto we have supposed that the recording instrument of Morse is worked directly by the line current. This is only done on short circuits, generally less than 50 miles. On long circuits, direct working could only be accomplished by an enormous sending battery. The loss by leakage on the way is very considerable, so that a current strong at starting loses greatly before it reaches the station intended; besides, the leakage becomes all the greater the greater the number of cells employed, or the greater the tension of the battery. It is found a much better arrangement to get the 'Morse' worked by a local current, which may be made as strong as requisite without any loss, and to include a very delicate instrument in the line circuit, which has only to make or break the local circuit. Such an instrument is called a relay, the principle of the action of which is shewn in fig. 136. Instead of the electro-magnet of the register being in the line circuit, the electro-magnet, E, of the relay is

included. The coil is long, and of thin wire, and a very faint current is sufficient to develop magnetism in the core. The line current passes through the coils of E just as it is represented doing through that of the Morse in fig. 131. The armature of the relay, A, is attached to a lever, *cc'*, moving round the axis *a*. When a current is sent through the coil, the lever is drawn down, and the end *c'* rests on the screw S. When there is no current, the elasticity of the spring *s* brings it back against the screw S'. The spring, *s*, is so adjusted that the play of *cc'* may be made as easy or stiff as the strength of the line current requires. The pillars N and P are connected with the poles of the local battery. The metal spring *s* places the lever *cc'* in conducting connection with P. The poles of the battery may therefore be taken to be the screw S, and the end *c'* of the lever. When these are in contact, the local current flows, and it stops when *c* is brought back against the insulated screw S'. The Morse is included in the local circuit. When a current comes from the sending station, the armature, A, is attracted, *c* falls on S, the local circuit is closed, and the Morse begins to print. When the current ceases, *c'* falls on S', and the style of the Morse is withdrawn from the paper. The effect is thus the same as if the line current printed, and not the local current. By this means, a current that would have no effect on the Morse, can complete the local circuit, and print most legibly.

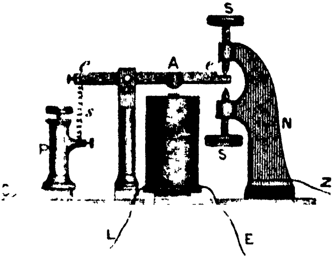


Fig 136.

155. *How several Stations are connected in one Circuit.*—This is effected in three ways—by an *open circuit* (Ger. *Arbeitsstrom*), by a *closed circuit* (Ger. *Ruhestrom*), and by *translation*. In all of these, each station may telegraph simultaneously to all the stations in the circuit, and if the message concerns them

all, a record may be printed at each station. When a station wishes to telegraph to another, it keeps signalling the name till the station in question signals back that he is ready. The others, finding that the message does not concern them, leave the two concerned in possession of the circuit.

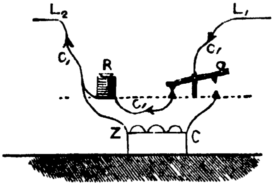


Fig. 137.

The arrangement of an intermediate station in an open circuit is shewn in fig. 137. L_1 and L_2 are the wires from the terminal stations; R is the relay; the rest mean the same as in fig. 133. The station is represented as receiving. The line current passes through the key, the relay R, and goes on to L_2. The relay sets the local battery and the register in operation. The line current is brought into the station, and led out without being affected. Electrically, it is the same as if it had gone on in the air direct from L_1 to L_2. When the station sends, the key is depressed. The current goes from C into the line L_1, is earthed at the one terminal station, leaves the earth at the other, and returns to Z by L_2. The battery here has no 'earth,' as at the terminal stations, the arrangement of which is as in fig. 133. An 'earth,' however, is generally put at each station, so that it may be worked as a terminal station if required. R at sending is out of circuit. According to this plan, every station must have a battery as strong as the terminal stations. In the closed circuit, no battery is needed at the intermediate station. If the battery and its connections be removed, fig. 137 gives the arrangement in a closed circuit. The battery may be placed only at one terminal station, or it may be divided into two, and a half put at each end—both, however, being joined up to act with, not against each other. The circuit is closed when no one operates, so that a current constantly flows. The keys breaking the connections stop it for the time. The relays act negatively, making the Morse print when there is no line current, and be at rest when it flows. If S′ in the relay (fig. 136) were uninsulated, and S insulated, it would act in a closed circuit. The advantage of the closed circuit is, that the batteries which require considerable attention are confined to the terminal stations, where they can be best cared for. Besides, little or no adjustment is needed for the relays. In the closed circuit, all the relays are in circuit at once. Open and closed circuits are used in lines where a number of smaller towns are joined together, the business of all of them being no more than sufficient to keep the line working. They are for short distances, seldom more than 200 or 300 miles.

When two stations, say 500 miles apart, are to be connected by telegraph, it is seldom done by a direct line, it being found more efficient to transmit to a half-way station, and thence to retransmit to the end one. The retransmission is effected not by manipulative skill, but by mechanical contrivance, so that, while the half-way station may read the message sent, no time is lost in the transmission, and the two end stations and the intermediate station communicate with each other as readily as if they were in an open or closed circuit. This mechanical retransmission is called *translation.* It is effected by making the lever of the register act as a relay in transmitting a message to the next station. The system, to be fully explained, would require more detail than we can here give to it. We shall only shew how translation can be effected, leaving out of account how all the stations can communicate as in one circuit. We also suppose, for the sake of simplicity, that no relay is needed, and that we are dealing with a direct working register. The current, C_1 (fig. 138), from the sending station enters the coil of the register M, and goes thence to earth P, and returns as shewn by arrow C_1. The register may record or not, according to the message, but its doing so or not in no way interferes with translation. The copper pole, C, of the battery is connected with the lever *ll'* of the register, and the zinc pole is to earth. When the lever

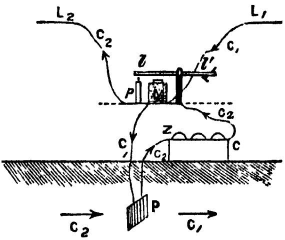


Fig. 138.

is drawn down by the current, C_1, it strikes against the point at the top of the pillar *p*, that checks its motion. The pillar *p* is joined to line L_2, running to the further station, and when the lever falls, a second circuit—namely, that of the battery—is closed, in which C, the lever, the pillar, L_2, the further station, the earth, P, and Z are all included. Thus, as *ll'* prints at the intermediate station, it at the same time sends a new printing current to the next. When it ceases to print, so does the register at the distant station. It is in this way that parliamentary news is transmitted simultaneously to all the important towns lying between London and Aberdeen. At the shore ends of submarine cables there is always a translating apparatus. This allows the cable to be worked by a battery suited to it, without loss of time in making it a special circuit.

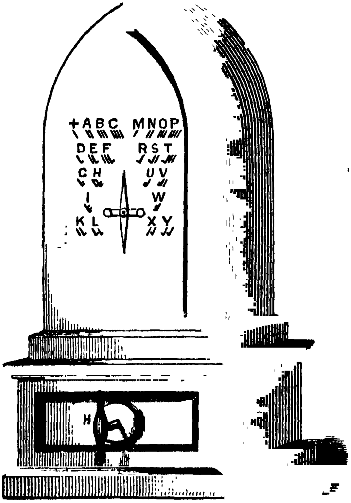


Fig. 139.

156. *Cooke and Wheatstone's Needle Telegraph.*—This consists of an upright galvanometer (88), with the astatic needles loaded at the lower end to keep them, when not acted on, in a vertical position. A front view of the single needle instrument is given in fig. 139, and a back or interior view in fig. 140. One needle moves within the coil OO, and the other on the face of the dial. It is the dial needle which acts as the indicator. The alphabetical code is made up by combinations of the right and left deflections of the needle. The old alphabet is given in fig. 139. A is made by two left

deflections, M by one right; D by one right, then one left; R by one left, then one right; G by two right, and one left; and so on. The short arm indicates which beat is made first, and the long that made second. The Electric and United Kingdom companies now adopt an alphabet corresponding to Morse's code, a right-hand deflection corresponding to a dash, and a left-hand deflection to a dot. The instrument is so arranged, that when the handle, H, stands erect, the whole is in the receiving state. When the handle turns to the right or left, the instrument sends, and the needle deflects accordingly to the left or right at both the sending and receiving stations. The instrument (fig. 140) has four connections: L, the line wire; E, the earth wire; C, the copper pole of the sending battery; and Z, the zinc pole. It is represented in the receiving position. The current takes the course L, *a*, the coil T, the spring *cd*, the metal points in the pin *p*, the metal spring *ef*, thence by *g* to earth. The handle in front works the cylinder PIN, which turns on the axis *n*. It is divided into three parts: those marked P and N are covered with copper, and are insulated from each other by the intermediate part, I, which is of ivory. By the spring *st*, which presses against it, P becomes the + pole of the battery, and by the spring *mi*, through the axis *n*, N becomes the – pole. A metal tooth, *k*, is fixed to P, and

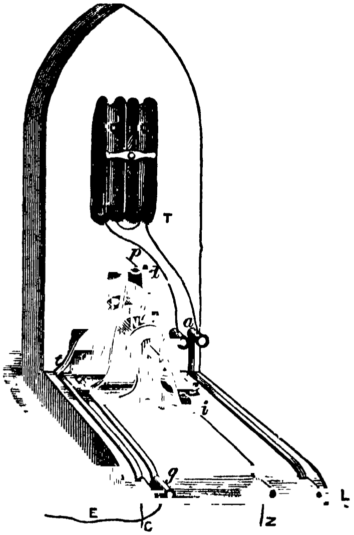


Fig. 140.

another, *h*, to N. These stand vertical, and are out of circuit when the instrument is in the receiving position. When a zinc (reverse, or negative) current is put to line, the handle, H, is so turned that *h* presses against the spring *dc*, and removes it from the point at *d*, thus breaking the receiving circuit. At the same time that *h* presses on *dc*, *k* presses on *or*. The reverse current takes the following course: Z, *i*, *n*, N, *h*, *c*, coil, *a*, L, distant station, earth, E, *g*, *r*, *o*, *k*, P, *s*, *t*, C. When the handle is turned the opposite way, *h* presses against *ef*, and *k* against another spring similar to *or*, on the other side of P, which is not shewn in the figure, and which is connected with the strip of metal *c*, and thereby with OO, and the copper (or positive) current is put to line. The cylinder PN acts as a commutator, sending a copper or zinc current, according to the side towards which it is turned. Sometimes two needles are placed in the same box, each having a separate line-wire to work it. The telegraphing can be much more expeditiously done with two needles than with one, as two deflections can be made at once, one on each instrument. The rate of signalling with a double needle is rather above what can be done by a Morse. Seeing that two wires are necessary for a double needle instrument, and that only one is necessary for a Morse, it is a much more expensive instrument. Single needle lines are much used for working railways, and for circuits with little traffic, but not for main telegraphic lines. The needle instrument is delicate enough to be worked direct without a relay. The dial of these instruments is movable, so that when earth currents deflect the needle to a position from the vertical, it is turned so as to keep the stopping pins equally distant from the needle. When several stations are joined on the needle system, the open circuit arrangement is employed.

157. *Chronology of the Electric Telegraph.*—Ampere suggested as early as the year 1820 the employment of a galvanometer, lines of wire, and a battery as a means of telegraphing. The first occasion on which this suggestion was carried out and put to practical use was in the year 1833, when Gauss and Weber at Göttingen, with a view to aid their magnetic observations, united the Observatory and Physical Cabinet, distant about a mile, by two wires suspended in air. The indicator was a

reflecting galvanometer, an instrument similar to that shewn in fig. 20, with the suspended magnet in the centre of a coil of wire forming part of the circuit. Their alphabet was made up of combinations of right and left deflections. This apparatus, the first ever employed for practical telegraphy, has lately, in the hands of Sir William Thomson, become the most sensitive of all telegraphic instruments. His reflecting galvanometer is the only instrument at present by which a cable, 2000 miles in length, may be worked with low tension (2 or 3 Daniell's cells). It consists of a magnetic needle, not more than a grain in weight, suspended by a thread without torsion within a sensitive galvanometer coil. A tiny mirror is attached to the magnet, by which a beam of light directed against it is reflected upon a scale at some distance. When no current passes, the reflected ray lights up the zero-point of the scale. When a current is sent, it travels to the right or left according to the message. If earth currents turn the reflected ray away from the zero-point, it is easily brought back by shifting the strong magnet placed outside the coil, intended to make the needle quickly settle. Gauss and Weber's telegraph was merely looked on as a scientific curiosity. It was not till the year 1837 that the electric telegraph promised to become a matter of general and practical importance. In that year three systems of telegraphy of independent origin were tried, and so nearly at the same time, that all three lay claim to priority. In June of that year, Cooke and Wheatstone patented a five-needle telegraph, and the patent was put in action on the Great Western Railway soon afterwards. These inventors have undoubtedly the credit of being the first to construct a line of telegraph for general purposes. Their lines consisted of underground insulated wires. Cooke derived his first ideas from a lecture he heard at Heidelberg given by Professor Munke, in which Baron von Schilling's horizontal needle telegraph was described, said to have been constructed as early as 1832 or 1833. In July of 1837, Steinheil, at Munich, stretched telegraphic wires over the houses of the town from the Physical Cabinet of the Academy to the Observatory of Bogenhausen, about three miles off. He telegraphed in three ways; by the deflections of a needle, by the sounding of two bells of different tones, and by printing a strip of paper. In October of 1837, Professor Morse exhibited his system on a line of half a mile in extent. Morse's system is at present more used than any other. Steinheil's printing system is also extensively employed, more especially on the continent. Steinheil's system of printing is different from Morse's; + and − currents print each a different mark. In Morse's system either current prints indifferently. Steinheil's alphabet consists of dots to the right and left of the strip of paper. It is thought that the telegraphing by right and left dots can be done more quickly than dots and dashes in a line. In 1838, Steinheil discovered the efficacy of the earth circuit and the need of only one wire. To Steinheil is also due the merit of being the first to stretch wires in air on insulating supports, and to shew the applicability of magneto-electricity to telegraphic purposes. Cooke and Wheatstone patented the first step by step telegraph in 1840. This invention was worked by voltaic or magneto electricity. In 1846, Bain patented his electro-chemical telegraph. In this instrument a piece of paper, moistened with an acidulated solution of ferrocyanide of potassium, is laid on a revolving plate of metal under a steel point pressing gently on it. As the current passes through the paper from the point to the plate it marks it with blue dots or dashes, as in Morse's system. No relay is needed. This system, to all appearance one of the most simple and delicate, has never come into permanent use. Morse's telegraph did not come into practical use till 1844, when it was used on the first American line between Washington and Baltimore. The first successful submarine cable was laid between Dover and Calais in 1851. Faraday first announced the effects of lateral induction in 1854. The telegraph was completed by the Persian Gulf to India in 1865. Four attempts have been made to establish telegraphic communication with America; the first in 1857, the second in 1858, the third in 1865, and the fourth in 1866. In the first and third, the cable snapped; and in the second, it was laid, but became useless in a few weeks. On the 27th of July 1866, Europe was telegraphically joined to America by a cable successfully laid between Valentia, on the coast of Ireland, and Newfoundland. The cable of 1865 was picked up, spliced, and completed, September 1—8, 1866. See Appendix. Telegraphs printing in Roman type have been tried, and are now gaining ground. Hughes's and Dujardin's are of this kind. Their action is at present not much superior to a simple Morse.

The Telephone.

158. This is an instrument for telegraphing notes of the same pitch. Any noise producing a single vibration of the air, when repeated regularly a certain number of times in the second (not less than thirty-two), produces, as is well known, a musical sound. In art. 115 we found that when a rod of iron was placed in a coil of insulated wire, and magnetised by a current being sent through the coil, it gave out a distinct tick when it was demagnetised by the stoppage of the current. A person when singing any note causes the air to vibrate so many times per second, the number varying with the pitch of the note he sings, the higher the note the greater being the number of vibrations. If we then, by any means, can get these vibrations to break a close circuit in which the coil just mentioned is included, the note sung at one station can be reproduced, at least so far as pitch is concerned, at another. Reis's Telephone (invented 1861) accomplishes this in the following way. AA (fig. 141) is a hollow wooden box, with two round holes in it, one on the top, the other in front. The hole at the top is closed by a piece of bladder, S, tightly stretched on a circular frame; a mouth-piece, M, is attached to the front opening. When a person sings in at the mouth-piece, the whole force of his voice is concentrated on the tight membrane, which in consequence vibrates with the voice. A thin strip of platinum is glued to the membrane, and connected with the binding screw *a*, in which a wire from the battery, B, is fixed. A tripod, *efg*, rests on the skin. The feet *e* and *f* lie in metal cups on the circular frame over which the skin is stretched. One of them, *f*, rests in a cup containing mercury, and is connected with the binding screw *b*. The third foot, *g*, consisting of a platinum point, lies on the

circular end of the strip of platinum just mentioned. This point being placed on the centre of the oscillating membrane, acts like a hopper, and hops up and down with it. It is easy to understand how, for every vibration of the membrane, the hopper will be thrown up for the instant from connection with its support, and how the close circuit is thus broken at every vibration. The receiving apparatus, R, consists of a coil of wire placed in circuit, enclosing an iron wire, both being fixed on a sounding box. The connections of the various parts of the circuit are easily learned from the figure. Suppose a person to sing a note at the mouth-piece which produces 300 vibrations a second, the circuit is broken at the bladder 300 times, and the iron wire ticking at this rate gives out a note of the same pitch. The note is weak, and in quality resembles the sound of a toy trumpet. Dr Wright uses a receiving apparatus of the following kind. The line current is made to pass through the primary coil of a small induction coil. In the secondary circuit he places two sheets of paper, silvered on one side, back to back, so as to act as a condenser. Each current that comes from the sending apparatus produces a current in the secondary circuit, which charges and discharges the condenser, each discharge being accompanied by a sound like the sharp tap of a small hammer. The musical notes are rendered by these electric discharges, and are loud enough to be heard in a large hall.

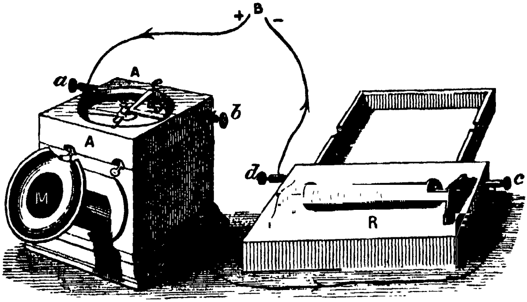


Fig. 141.

APPENDIX.

Wilde's Magneto-Electric Machine.

Mr H. Wilde of Manchester has lately patented a magneto-electric machine, which, with a sufficient expenditure of mechanical energy, can be made to furnish any amount of current electricity. It accomplishes this with a simplicity and economy hitherto unequalled, and it promises thereby to extend immensely the practical importance of electric science.

The machine is founded on a new and somewhat paradoxical principle—viz., that *a current or a magnet indefinitely weak can be made to induce a current or a magnet of indefinite strength.* A general description will best shew how this is proved and applied.

Fig. 142 shews a front elevation of a 7-inch machine, constructed for the Commissioners of Northern Light-houses. It consists of two separate machines—a purely magneto-electric machine, and a machine which is both electro-magnetic and magneto-electric. Both machines are in the main very similar, and in many respects identical, the only difference being in size and power. The smaller machine, MM′, which is purely magneto-electric, is seen surmounting the other. The horseshoe permanent magnet, MM′, is the foremost of a series of sixteen similar magnets, placed the one behind the other in a horizontal row. Each weighs 3 lbs., and sustains a weight of

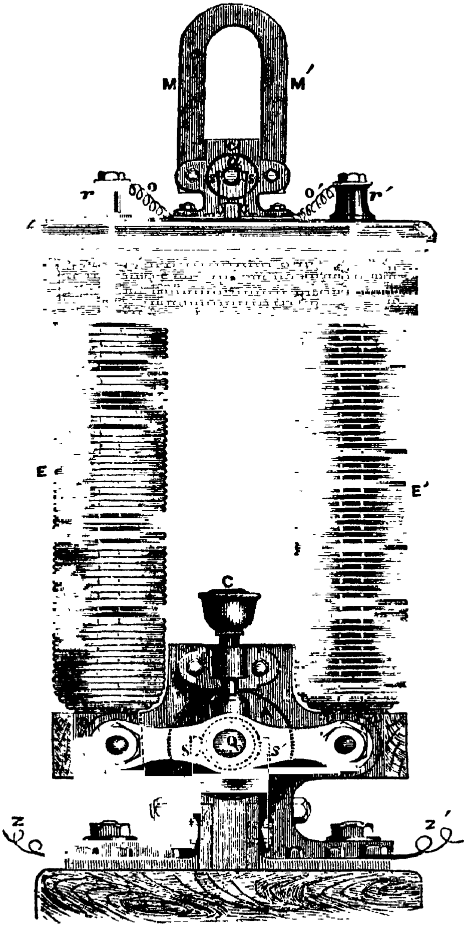


Fig. 142.

20 lbs. The sixteen magnets are fixed below to the *magnet cylinder*, *c*, shewn on a larger scale in fig. 143. This is partly made up of cast-iron, partly of brass. The two iron components, *ii* (fig. 143), form the sides of it, and the brass bars, *bb*, lie between them. They are bolted firmly together by the brass bolts, *rr′*. The magnet-cylinder is about 12 inches in length; in the centre of it is accurately bored a circular hole, extending the whole way, 2½ inches in diameter. The inner side surfaces of the magnets below are accurately fitted to the upright plane sides of the magnet-cylinder, and are firmly secured to it. By this means the cast-iron portions of the magnet-cylinder, *ii*, form the polar terminations of the magnetic battery, the brass bars, *bb*, between them, breaking the magnetic continuity.

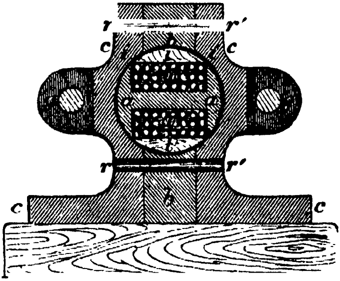


Fig. 143.

A cylindrical armature, *aa*, of cast-iron is made to revolve within the magnet-cylinder. Its diameter is $\frac{1}{70}$th of an inch less than the diameter of the cylinder, which enables it to revolve without friction in very close proximity to the polar surfaces. The manner in which it is centered is, for the sake of simplicity, not shewn in the upper machine, but it is shewn in the lower machine, where, as is afterwards mentioned, the construction, though larger, is perfectly similar. The framework for sustaining the axis of the armature is firmly bolted at *gg*. Fig. 143 gives, as just mentioned, an enlarged cross section; fig. 144 shews an enlarged side-view. Two rectangular grooves, *wl*, are made on opposite sides, giving to it somewhat the appearance of a rail. About 50 feet of insulated copper-wire, *ww*, is wound lengthwise into these grooves in three coils (shewn in section, fig. 143). The coil thus formed is shut in by wooden packing, *ll′*. In fig. 144 this packing is removed from the two ends to shew the longitudinal winding of the coil. To prevent the wires from being driven out by the centrifugal force generated in the rapid rotation of the armature, straps of sheet-brass encircle the armature at regular intervals, and are sunk in grooves prepared for them in the cast-iron. Two caps of brass, *kk*, are fitted to the ends of the armature, and to these are attached the steel journals or axes of rotation, *ff*. On the further axis (the back axis of fig. 142) the pulley, *m*, is fixed, round which passes the strap from the steam-engine which works the machine. On the other axis (the front axis of the figure) two rings are put, one, *n*, insulated from it, and the other, *n′*, connected with it. One end of the armature coil is in connection with the armature, and thereby with the axis and *n′*, the other end, is insulated and fixed by a binding-screw with *n*—*n* and *n′* are thus the terminals of the coil. They are made of hardened steel, and the springs, *s* and *s′*, which press against them are of the same material.

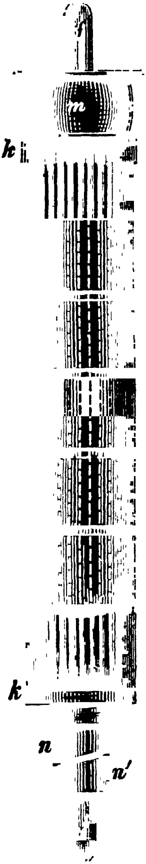


Fig. 144.

Starting from the position shewn in fig. 143, the armature in one revolution induces two opposite currents in the coil, one in the first, the other in the second half-revolution (122). It will be seen (fig. 144) that the separation between *n* and *n′* lies obliquely. In this way, each spring, *s* or *s′*, presses against a different ring at each half-revolution. As *n* and *n′* change their electric sign, it is so arranged that they change the spring, *s* or *s′*, against which they press. Thus *s* and *s′* receive their currents always in the same direction, consequently the wires, *o* and *o′*, convey the current away from the machine in a uniform direction. The armature is made to revolve 2500 times per minute, and 5000 waves or currents of electricity are transmitted to the wires, *o o′*.

Thus far we have nothing essentially peculiar in Wilde's machine. The construction of the magnet cylinder is quite novel, though the position of the armature, which is decidedly the most advantageous, is not new, as it was adopted several years ago in Siemens and Halske's magneto-electric machine. One advantage of this position lies in the motion of the armature not being resisted by the air. In the ordinary position of the armature (fig. 116), much of the work applied to the rotation is expended in the armature beating the air.

There is no such loss in Siemens and Halske's or Wilde's machine. Another advantage is derived from the inductive action of the magnet being exerted directly on the coil, as well as through the intervention of the armature. If the coil were made to rotate without the armature, currents would be induced in it of the same kind as that induced by the armature, though of feebler intensity, the maximum points of which would occur when the coil was moving through the line joining the poles, and the minimum points when it was at right angles to that position (124—126). Now these are the converse of the maximum and minimum induction points of the armature (123). In the position in which the armature is placed in this machine, both armature and coil contribute to the current, the one most when the other gives least, and *vice versâ*. The same advantage is not secured by the ordinary construction.

We come now to describe the singular peculiarity and merit of Wilde's machine. The current got from the magneto-electric machine is not directly made use of, but is employed to generate an electro-magnet some hundreds of times more powerful than the magnetic battery originally employed, by means of which a corresponding increase of electricity may be obtained. This electro-magnet, EE′ (fig. 142), forms the lower part of the figure, and by far the most bulky portion of the entire machine. It is of the horse-shoe form, E and E′, forming the two limbs of it. The core of each of these, shewn by the dotted lines, is formed by a plate of rolled iron, 36 inches in height, 26 inches in length, and 1 inch in thickness. Each is surrounded by a coil of insulated copper wire (No. 10) 1650 feet long, wound round lengthwise in seven layers. The current has thus, in passing from the insulated binding-screw, *r*, to the similar screw *r′*, to make a circuit of 3300 feet. Each limb of the electro-magnet is thus a flat reel of covered wire wrapped round a sheet of iron, the rounded ends alone of which are seen in the figure. The upright iron plates are joined above by a bridge, P, built up also of iron-plate, and are fixed below the whole way along with the iron bars *v*, *v* to the sides of a magnet cylinder of precisely the same construction as the one already described. The iron framework of the electro-magnet is shewn by the dotted lines. The depth of the bridge is the same as the breadth of the bars, *v′*, *v′*, which are of the same size as the bars, *v*, *v*. The various surfaces of juncture in the framework are planed so as to insure perfect metallic contact. The upper and lower machine are in action precisely alike, only the upper magnet is a permanent magnet, and the lower one an electro-magnet. We have the same magnet cylinder, I, I, the same armature, A, and springs, SS′, and the same poles, ZZ′; the size is, however, different; the calibre of the magnet cylinder is 7 inches. The diameter of the lower armature gives the name to the machine—viz., a 7-inch machine. Figs. 143 and 144 are on the scale of the lower machine (fig. 142). The length of wire on the lower armature is 350 feet. It is 35 inches in length, and is made to rotate 1800 times a minute. The cross framework attached at *gg* to the magnet cylinder, in which the front journal, *f*, of the armature rotates (at Q), is shewn in the lower machine (fig. 142). When the machine is in action, both armatures are driven simultaneously by belts from the same countershaft. For the electric light, the currents conveyed to the springs, S and S′, need not be sent in the same direction (140). In that case, the separation between *n* and *n′* is vertical; and each spring presses against only one ring during the whole revolution, receiving and transmitting each revolution two opposite currents. Oil for the journal and commutator is supplied from the cup C.

The machine here described is intended for a three-horse-power steam-engine, but more power might be expended on it. A larger engine could drive the smaller armature faster, and thereby cause much more energy to be expended, and more electricity to be induced in turning the lower armature than with a power of three horses. The machine, when worked with a power of three horses, will consume carbon sticks three-eighths of an inch square, and evolve a light of surpassing brilliancy. With a machine that consumes carbons half an inch square, a light of such intensity is got, that when put on a lofty building it casts shadows from the flames of street-lamps a quarter of a mile distant upon the neighbouring walls. The same light at two feet from the reflector darkened ordinary sensitised photographic paper, as much in twenty seconds as the direct rays of the sun at noon on a clear day in March in one minute.

Mr Wilde furnishes for the electro-magnet cylinder of many of his machines two armatures: one an ‘intensity armature,’ similar to that just described; the other a ‘quantity armature’—one of which may be easily substituted for the other. The quantity armature, instead of insulated copper-wire, is enveloped in folds of insulated copper-plate, or ribbon, which, offering little resistance, a current of much greater quantity, though of less tension, is given off. It is with the quantity armature that experiments in the heating power of the machine are best performed. With a 10-inch quantity armature Mr

Wilde succeeded in melting an iron rod 15 inches long and ¼ inch thick.

Wilde's machine enables us to convert any amount of mechanical energy into electricity. By increasing the size of the electro-magnet, or by using a second electro-magnet, induced by the first, an unlimited amount of energy can be expended, and so converted. The size and weight of the apparatus are also small. The entire machine just described is under 5 feet in length and height, is 20 inches wide, and weighs a ton and a half. Mr Wilde also contemplates making a smaller machine, useful for lectures and institutions, to be worked with the hand, which will form a ready and convenient substitute for the galvanic battery in electric experiments.

Mr Wilde attributes the power of his machine to the power that an electro-magnet has of 'accumulating and retaining a charge of electricity in a manner analogous to, but not identical with, that in which it is retained by the Leyden jar.' The polar terminals, for instance, of a very large electro-magnet can be made to give a bright spark 25 seconds after all connection with the exciting magneto-electric machine has been broken.

Construction of Induction Coils.

In article 120 the general construction of the induction coil is described. As this instrument is every year becoming of greater practical utility, a few details in further illustration and amplification of what is there said will not be out of place here. The coil of the secondary bobbin is exposed to very different tensions throughout its length. The middle of the wire, when the coil acts in the usual way, has no tension, and may be taken as the neutral ground between the + and − electricities of the halves, the tension on each of which increases as the pole is approached. The tensions reach a maximum at the poles. The electricities of each half have a tendency to strike into each other, or into the primary coil, or other part of the bobbin connected with the ground. Even two successive portions of the same half have the same tendency, for a less + stands as a − to a more positive, and a less negative is + to a more −. The object therefore to be aimed at in the insulation is to prevent either of the electricities from sparking into each other or into the ground. In the ordinary construction the wire is coiled first round the centre of the bobbin all the way along, and layer after layer is put in regular succession the one above the other, with insulating material between. In this way the greatest tensions are in the inside and on the outside layers, the poles coming directly from them. In this arrangement it is extremely difficult to maintain proper insulation. The utmost care is needed to keep the electricity of the inmost layer of wire from leaping into the primary coil, and even when this is fully accomplished, there is a Leyden-jar action between the inmost layer of the secondary and the outmost layer of the primary coil which hinders the free delivery of the electricity at its pole with which it is charged (121). The neutral point of the secondary wire is put nearly midway between the inside and the outside of the coil, at a place where the insulation is best, and least needed. We shall mention two ways of obviating this defect.

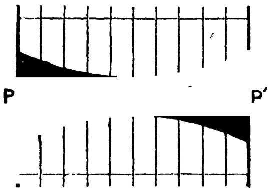


Fig. 145.

Fig. 145 is intended to shew the construction of the celebrated coil constructed by Siemens and Halske, and exhibited at the Exhibition of 1862. PP is the hollow tube in which the primary coil is put. The bobbin is made of ebonite, and the central part is thickest at the ends and thinnest at the middle, being 26 millimetres at the ends and 12 at the centre. It is 95 centimetres in length. To this tube are cemented 150 thin discs (only a few are given in the figure) of ebonite at equal distances, dividing the whole length into compartments. Each compartment is filled up with copper wire ·14 of a millimetre thick, covered with silk and varnished. The various compartments communicate with each other, so that the whole wire is continuous from end to end. The length of the whole is 129,000 metres. The silk and varnish on the wire are sufficient insulation between the convolutions in each compartment, and the discs are proof against the spark striking through between them. The coil may be thus said to be insulated, as it were, wholesale and retail. The insulation of the various parts from each other is thus complete. As regards external insulation, least is required for the middle compartments, where the tension is least, and there is least danger of the electricity breaking through into the primary coil. The tension of the end compartments is greatest. Accordingly, the tube is thinnest at the middle and thickest at the ends. The thickness at the ends not only prevents the electricity striking through, but lessens the Leyden-jar action between the ends and the primary coil. With one Bunsen cell this coil gives a spark of 21 centimetres; with six cells, one of 58 centimetres in length.

The section of the bobbin of a secondary coil (17 inches in length), of much smaller size and of a less expensive character, is given in fig. 146. The coil of which it forms a part was made by Mr Hart of Edinburgh, under the author's direction, and was lately exhibited before the Royal Scottish Society of Arts. The central tube, PP, is of hardened wood; *d*, D, and *d′*, are thick discs of gutta-percha cemented to the tube. The wire is coiled in two portions, beginning at the middle, *m*; the one half being coiled to the right, the other to the left. If the whole could be seen, it would look like one coil from end to end with a disc in the middle. The two halves communicate by a wire piercing the central disc at *m*. Gutta-percha paper is wrapped round the tube to a thickness of more than a quarter of an inch before the wire is wound on. Each consecutive layer of wire (copper covered with silk) is separated from the one above or below by two or three sheets of gutta-percha paper. The coil has the greatest thickness at the middle, and tapers off to the ends. This is done in conformity with a principle discovered by Jacobi and Lenz (1844), namely, that in an electro-magnet, where the wire is uniformly distributed over its length, the inductive power is greatest at the centre and becomes feeble at the ends. It is sought in this coil to proportion (approximately) the length of the wire coiled in different parts of the bobbin to the electro-motive force of the primary coil at that part. In this way the quantity of electricity given off by each part of the coil should be the same (95). The ends of the primary coil, where the inductive force is least, are left free. The sparks given off by this coil, which are nearly seven inches in length (with six Bunsen cells), are peculiarly dense, the quality aimed at in the construction. The length of the wire is about seven miles.

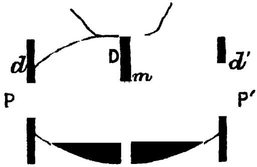


Fig. 146.

The double form of the bobbin throws the middle of the wire next the primary coil. Here the tension being least, there is little or no danger of the electricity sparking into the primary coil. As the wire leaves the centre it increases in tension, but as the tension rises, the insulation from the additional sheets of gutta-percha paper between the different layers is also increased. The tension is thus placed where it can be best withstood. The electricities of the poles are kept from uniting by the thick central disc (1 inch thick and extending 1½ inches beyond the coil), and a considerable thickness of gutta-percha placed over them. Within the coil they are kept apart by all the gutta-percha paper on each half of it. To prevent the gutta-percha from altering in the presence of the air, which it usually does, the whole is enclosed in a layer of melted paraffin. As the wire is symmetrically coiled, each terminal has exactly the same power, a feature never seen in the usual construction.

For large coils, mercury-breaks or rheotomes are almost always employed. A wire is made to dip into a cup of mercury and lifted out alternately, so as to make and break contact in the primary circuit. The interruption thus made is much improved by pouring alcohol over the mercury; the spark of the extra-current (119) taking place with more difficulty in alcohol than in air. As pure mercury, when thus used, is apt to be broken up into globules under the constant motion, an amalgam of silver or platinum, of a treacly consistence, is substituted with advantage. The mercury-break, sketched in fig. 147, and used by the author in conjunction with the coil just described, works with singular steadiness and efficiency. A spiral, *ss′*, of No. 13 copper-wire is made of about an inch in diameter, and six inches in length, is stretched out to about nine inches, and soldered to two rings on the rod *p*, half an inch in diameter. To shew the construction more clearly, the convolutions are shewn few and far apart. In the apparatus itself the spiral hides almost entirely the rod beneath. The rings being wider than the rod, keep the spiral free from it. The lower ring, *b*, is

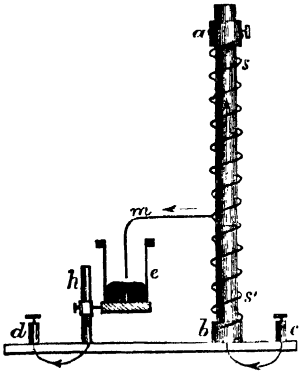


Fig. 147.

insulated from the rod; the other, *a*, being fixed by a binding-screw to it, is in conducting-connection with it. The rod is partly of iron, partly of brass, and communicates with the binding-screw, *c*. A wire, *m*, is soldered to one of the convolutions a little above the end of the iron part of the rod, and comes out at right angles. It is turned down at the end, so as to dip into a cup of mercury, *e*, which communicates by the pillar, *h*, with the binding-screw, *d*. The break is on a separate stand from the coil, and is so placed in the primary-circuit that each binding-screw is connected with a coating of the condenser. When the commutator turns the current on, the spiral is gently moved by the hand, and if the wire dips into the mercury, continues in constant oscillation. The cup is raised or lowered till the point is got where the best sparks pass between the terminals of the coil, and fixed there with a binding-screw. A spiral, so hung, forms a delicate pendulum, which only requires a small force to keep it in steady motion up and down. This the electric and magnetic action supplies. When the current passes, it goes from *c* up the rod, down the upper part of the spiral into the cup, and thence to the binding-screw, *d*. The iron rod becomes magnetic, and tends to send the various convolutions at right angles to the lines of magnetic force (111). Moreover, the various convolutions are the seat of a current moving in the same direction in all, and they consequently attract each other (fig. 93). Under this double action, the dipping-wire is lifted out of the mercury, and its own elasticity brings it back, again to complete the circuit, again to be lifted out, and so forth. A reversal of the current, causing a reversal of poles, the action of the spiral is indifferent to the direction of the current. To prevent oxidation, the part of the wire that dips should be of platinum. The alcohol on the surface must be more than an inch deep, otherwise it is scattered about in all directions by the breaking spark. If not, the vessel must be closed with a lid.

Such a spiral as the one just described is comparatively stiff, and cannot be regulated, in the manner afterwards described, so easily as one of thinner wire. The number of convolutions being small, and the spiral stiff, it requires a strong current to work it; being short, however, it adds almost no resistance to the primary circuit. If the spiral be made of finer wire, it can be made to work with a very feeble current, but then the resistance it introduces into the circuit is considerable, and this ought to be as much as possible avoided. In fig. 148, another form is given of this spiral break. Here the spiral is worked by a separate cell, and is not in the primary circuit of the coil. The spiral is of the same height as the other when closed and distended, but of finer wire ($\frac{1}{20}$th of an inch)—its diameter also is less. It admits of easy regulation. The arm, *h*, which can be fixed to the pillar, *k*, can be inserted into any part of the spiral, so as to lessen the oscillating part of it; to shorten, in fact, the pendulum. The shorter the acting part of the spiral the quicker does it oscillate, and thus any alteration in rate can be got. In this arrangement there are two cups, and the projecting wire has two dipping portions, one for each, which rise and dip simultaneously, or nearly so, according to the adjustment of the cups. The spiral circuit is exactly the same as before. The coil-circuit, connected with the apparatus, consists of the two cups and the wire fork, *nof*, and it is complete each time the ends of this fork dip into both. The cup, *e*, and the wire, *f*, are common to both circuits, but there is thereby no confusion or opposition of currents whatever be the direction of the currents transmitted. The cup, *l*, is easily adjusted, so that the dipping-wire, *n*, leaves the mercury just before *f* does so, and thus the break in the coil-circuit is effected only in the cup *l*. The course of both currents is marked; that of the spiral by dotted, and that of the coil by full lines. When the dipping-wire of this spiral just touches the surface, it begins to move of itself without the aid of the hand.

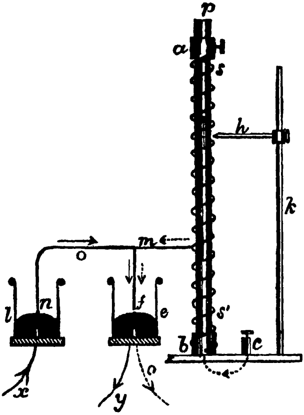


Fig. 148.

Electricity and Electric Force.

The remarks made by several scientific journals, with regard to the electro-static theory adopted in the preceding pages, render some supplementary statement desirable. The two points to which exception has been taken are, that electricity has a molecular action, and that it is an inductive force. With the present imperfect knowledge of the physical nature of electricity and of force, we cannot arrive at a satisfactory conclusion on all points; we wish only to shew, that so far as we can judge, these principles, carried out to their full extent, are consistent with the established laws of the science.

That Electricity is an Action among Molecules.—In articles 29 and 30, it is shewn that bodies are charged and discharged by an equal amount of opposite electricities disappearing or becoming neutralised when near enough to communicate with each other. Electricities, whatever they may be, never in one case can be traced to enter the body; they always leave it, and disappear at spark or contact. When they cannot communicate with each other, both electricities exist in them to the same amount, and the bodies remain in the polarised condition. Faraday has shewn, beyond question (32), that the particles of dielectrics, which take minutes or days to communicate electrically with each other, are in a state of polarity before discharge, that is communication between them, takes place, or while their insulating action lasts. The polarised state invariably precedes discharge, shewing that bodies have a separate power of transmitting polarity distinct from that shewn in spark or contact; they possess, in fact, two powers —that of polarising and that of neutralising, the former always preceding the latter. The polarising force appears instantaneously throughout the circuit, the polarity of each molecule being a necessary condition to its appearing in all. The velocity of discharge is dependent on the conformation of the circuit (38, 50, 152). How or why the molecules of matter have these powers, no attempt is made to explain; but that they have them, is matter of fact. The size of the bodies makes no difference in this action, a huge mass or a microscopic particle acts precisely alike. How otherwise, then, can we think than that the molecules of which masses are composed have precisely the same properties, only there may be something ultimate in their action, which, if known, would explain why and how they so acted? The molecular theory of electric action explains satisfactorily how conductors and non-conductors are alike in kind; how a charge can only reside at the boundary of a conductor and non-conductor, or, which is the same thing, on the surface of the conductor; how the charge resides in a dielectric, how the polarity of the galvanic circuit is effected, and how the battery current originates in and effects chemical action. Indeed, it seems so necessary to the comprehension of these, that it wears more the appearance of fact than theory.

That Electricity is an Inductive Force.—We consider the separate powers or polarities of electrified masses or molecules to be inductive forces, inasmuch as when the opposite polarities are separated, they ever remain the same in amount until they meet and neutralise each other. The reason for holding this opinion will be best shewn by an experiment like the following. Referring to fig. 36, we find that the charge on the ball hanging inside the pail induces a similar charge on the outside. Let us introduce a second insulated ball without charge. On making the two touch, the charge is divided between them, but no change is thereby effected on the gold leaves outside. Similarly, any number of balls may be introduced without any change on the leaves. Beginning again with the one charged ball, let us for an instant remove the ball without discharging it, and introduce into the pail a thick pail of shellac that nearly fills up the space between the ball and the pail. On placing the ball within the pail thus compounded, the leaves return to their former place. If, instead of a thick pail of shellac, we had made use of one of metal, no difference would be found on the outside charge. We thus find that extent of surface over which a charge is diffused, or lessened inductive resistance as that offered by the thick shellac or metal pail, makes no difference on the inductive power of the charge. By no device can we lessen or increase the quantity of electricity induced by a charge. The energy or work-power of it may alter, and we have reason to believe that it is lessened in both cases, as may be gathered from what follows. Let us now take a case where inductive force appears to fail with the same charge. I receive a 12-inch spark from an electric machine on the knob of a Leyden jar; I then take the discharging-tongs and discharge the jar. The spark I now get is under a quarter of an inch. Is there no inductive force lost here? We say no. The inductive force which acted between the ball of the machine and that of the jar, instead of taking only one direction, works through the dielectric glass, which is much more favourable for its action; the inductive action is diverted, not destroyed. The quantity of electricity induced outside the jar and in surrounding conductors is precisely the same. If we could remove the coatings from the jar without discharging them, and crumple them up into the dimensions of the original balls, we should get the same spark as before. Or, had we passed the first spark through a solution of copper by means of electrodes, and done the same with the jar spark, the amount of copper deposited would, in both cases, be exactly the same. But it may be said so much work must be done to push each electricity in the crumpling up in upon itself against its repulsive power. Such is undoubtedly the case ; and we must now proceed to shew the relation of this inductive force and work. Before doing so, let us plainly understand what we mean. Suppose we have two discs touching each other, which, by the action of some force, assume opposite and equal electricities on their surfaces of contact. We have thus only one section polarly electrified. Let us now pull the discs away parallelly from each other, and suppose for the moment, for the sake of simplicity, that their inductive action is not diverted from each other into neighbouring channels—and it is seldom otherwise in battery circuits—but that it remains concentrated between them; that we have, in fact, a uniform electric field between them. We have still the same amount of electricity in the discs ; but instead of having one section so affected, as at first, we have now myriads of sections formed by the contiguous surfaces of the molecules of intervening air, each possessing the same charges as the original discs when together. The amount of inductive force here on the original discs is unaltered, but we have immeasurably more force brought into existence in the intervening air. Whence this has come will be explained in the next section.

The Relation of Electricity to Work.—Quantity we consider to be the amount of electricity in one section of the chain, and inductive force refers to the fact that the quantity in each section is the same, however distributed. Quantity in depth, as well as in section, is, according to our views, proportional to work in the same medium, but has a different value in different media. In the case of the discs just mentioned, we conceive that the work expended in drawing them away is converted, according to our theory, in multiplying the number of charged sections. Whatever heat would be obtained by discharge, or the conversion of electricity into heat, of the two discs when close together, as much more heat would be obtained if discharge took place along the whole line when they were apart as there are different sections. If I lift the one disc from the other when affected only by gravity, the energy it acquires is stored up in itself, and it would make good that energy if allowed to fall. When I lift it up under the action of electricity, the energy, according to our views, is not stored up in itself, but in calling into existence polarised sections of the same mechanical value as the first two, in the parallel layers of air. This energy would be made good if the molecular powers could neutralise and convert themselves into heat, or they would give back their energy in drawing the upper to the lower disc, thereby throwing themselves out of circuit and generating motive energy in it. Substances differ electrically, and if the two discs were drawn apart in a medium less specifically inductive than air, the amount of work expended in the same distance would be proportionately increased. The increased energy of the sections thus formed would make itself good in the increased heat of discharge. The mere electrification of any section to the same inductive point, or to the same quantity, is no indication of its work-doing or heat-giving power. Each different substance has a separate mechanical value for the same amount of electricity. Returning again to our first medium, let us double the charge of the discs, and then draw them apart; to lift the upper disc to the same height as before, four times the work must be done, for not only is the force at each point doubled, but a double amount of it has to be generated in each layer as the disc rises. Similarly it could be shewn, if the discs were reduced to half the size, the work would be doubled with the same charge. Taking this, then, as the action in a uniform field where the tension does not vary, we draw the following conclusions.

The mere presence of electricity or electric quantity on any surface does not indicate work. When we have the same amount of charge in each section, the work varies directly as the length of the chain, as the resistance the material offers to induction, and as the tension. We estimate work by the product of quantity or amount of electricity on the end section, and the electro-motive force, viz., the work-power of a row of molecules in length or disposed as a normal (perpendicular) to the surface, that is, $w = qe$ (131). Practically, we must estimate e by the tension and extent of the end surface in reference to r, the inductive resistance of the chain, or that which gives to the total amount of electricity its work-value; thus $e = qr$, and w, accordingly, equals q^2r, or $\frac{e^2}{r}$. We consider the two discs and cylinder of particles between to be the same as the whole or a portion of the inductive circuit of a galvanic battery before each discharge. As the battery can charge the chain as often as it is discharged, q becomes s, or the quantity passing in a given time; r the conductive resistance; and e, instead of being instantaneous, is continuous. It is easily seen, moreover, that the electro-motive force varies in a circuit though the current does not (63). The total electro-motive force of the battery is divided, at inductive charge, among all the sections of the circuit, and apportioned to all alike if the circuit be uniform, but to each different part according to its resistance if it be not. The above equations also hold for electric action in air between bodies whose distance does not alter. With the same electro-motive force when the discs above referred to are reduced in size, when the distance between them is increased, or when a worse conductive or inductive material lies between them, the quantity is proportionately reduced, and as these are considered to constitute resistance, Ohm's law follows as a necessary consequence.

Tension, Potential.—By tension is meant (36) what is called in the fluid theory electric density, or the quantity of electricity on a unit of surface. This may be, by the aid of a condenser, anything with the same cell or battery. In article 72 it is mentioned that the electro-motive force is measured by its tension. It is evident that when electro-motive forces are compared, the tensions must be in similar circumstances, or before the same resistance. The word tension, although strictly applicable only to electric density, is generally looked upon as being on a freely insulated body, in which case it implies a certain work-power between the body and the ground, or with regard to a very considerable resistance. It is therefore necessary to be careful in the use of the word, so that its import may not be misunderstood. Before the same resistance the tension, or charge on a unit of surface, given by different electro-motive forces varies as the forces.

On a ball of given radius insulated in air, a unit quantity of electricity implies a certain work-power between it and the ground. In consequence of diffusion, the quantity in each molecule rapidly lessens as the perpendicular leaves its surface, the decrease being as the square of the distance, and the twin unit we must find in some large portion of the ground, where the charge in each molecule is next to nothing. We have thus, practically speaking, only the force of the insulated unit to take into account, the work-doing power of which is accordingly proportional to the square of its tension. The force of attraction or repulsion is also as the square of the tension (44), so that we may say the work-power of the given ball is as its attractive or repulsive force.

Instead of the word tension, used with reference to the work that can be effected by a charge when openly insulated, or electro-motive force, the word *potential* is now used, which is not open to the objection of a double meaning. 'The potential,' according to Sir William Thomson, 'at any point in the neighbourhood or within a charged body, is the quantity of work that would be required to bring a unit of positive electricity from an infinite distance to that point if the given distribution of electricity remained unaltered.' If the point here named be +, the potential will also be positive; but if − it will be −; that is, the work will be done and not expended in the transfer. The potential, P, of an insulated ball (radius k) in an open space with a charge, $q = q \div k$.

The *electro-static capacity* of an insulated body is the reciprocal of the resistance it is placed in. The capacity (c) is the ratio of the quantity (q) the body contains when charged at an electro-motive force (e); thus $c = \frac{q}{e}$. When one sphere (radius $= x$) is placed within a hollow sphere (radius $= y$), the inner being insulated by air from the outer, which is connected with the ground; then $c = \frac{xy}{y - x}$. The former equations, when stated with regard to c, are $q = ce$, $w = e^2c$. Speaking generally, the larger the surface of the body, and the thinner or better the dielectric layer between it and the ground, the greater is its capacity (37); c, for a ball in an open space varies as k.

In illustration of the fact that mere charge does not imply work, we may take the following. I take a battery of ten cells, and one cell of the same kind, and put in each case, say the zinc pole to earth, insulating the other poles. I use a condenser, such as that shewn in fig. 59, which, let us suppose, is delicate enough for my purpose. Some form of the torsion balance is, however, much better adapted to such a purpose. I charge the lower plate with the battery pole without using the upper plate. I see the divergence of the leaves. I do the same with the one cell. I find the gold leaves ten times more distended in the first case than in the second—that is, supposing the angles small. This indicates ten times the tension in the one case as in the other (strictly the tensions are as the sines of half the angle of divergence, or, more correctly still, the tensions are determined by an experimental graduation). I now use the upper plate with the one cell, and things might be so arranged that the plates condense tenfold. I withdraw my finger from the upper plate, then the pole from the lower, and finally lift off the upper plate, and the leaves indicate a tenfold tension. Thus the single cell appears to do as much work as the ten. The power of the plates to generate heat or do work by a discharge is small, and I have forcibly to lift away the upper plate—do additional work, in fact, before the power of the lower plate is what it was when charged directly by the ten cells. We know that in a conductive circuit the one cell, before a certain resistance, would do ten times less work than ten cells before a tenfold resistance. The work in lifting off the upper plate is therefore partly spent in making up the difference.

From what has been said it will be seen that we look on quantity in the same medium as charge in section, and electro-motive force as charge in depth. A rectangular prism of polarised particles, for instance, might have three quantities corresponding to its three different faces, and three electro-motive forces being the depths in each case. The line of action in which the prism occurs will determine which is the quantity and the electro-motive force. The quantity thus determined cannot be altered for the same action. It follows that if a second prism were to participate the charge of the first, there would be a loss of half the total quantity or work. For although on the double face which constituted quantity there was the same charge, yet the quantity in depth or electro-motive force was halved. Again, if the participating prism was placed in length, the total quantity and work would be again halved, for the quantity in section would be halved, while the quantity in depth remained the same. If in either case this was effected, there would be found to be conductive discharge somewhere accounting for the loss of work. To illustrate the bearing of our theory, we may fancy the total amount of wire in the armature of Wilde's machine to be such a prism, each particle of which had a definite amount of electricity and of work-force. If the whole were solid, the quantity would be represented by the section at right angles to the axis. In that case it would be prodigious; but the quantity in depth but twice the length of the armature. But if it was divided into a thousand different insulated wires, the quantity in section would be represented by the section of the wire, and that in depth by the length of the coil. An equivalence of this kind is certainly illustrated by the quantity and intensity armatures of the machine. If any distinction is to be drawn between electro-motive force and electricity, we would say that it was that energy which, diffused through a consecutive series of molecules, had been converted into electricity, and which the electricity so formed is prepared to give back, inductively in electricity, or conductively in heat or other form of energy. As, however, the work spent in electricity is equal to the work that the electricity can spend, we speak indifferently of the electro-motive force of a battery or of a charge given by it. If, in any circuit, we have a unit charge in surface with a unit work-value for the whole, the electro-motive force of each row of molecules is also unity.

Electricity and its Correlations.—That friction (24), chemical action (58), heat (133), and mechanical action (122, 52) can be converted into electricity has been already treated of. These, moreover, have apparently a definite equivalent proportion to electricity. Thus, so much zinc dissolved in the battery, so much heat radiated to the thermo-electric battery, and so much mechanical energy spent in the magneto-electric machine, are each attended with the production of a certain amount of electricity. Conversely, electricity can produce chemical action (102), light (46, 101, 121), heat (100, 135, 126), mechanical energy (87, 107, 142, 143), and electricity itself, either as magnetism (113), as statical electricity (28, 52), or as current electricity (116).

The equation, work equals quantity into tension or electro-motive force, is shewn in current and magneto-electric induction. In the primary circuit of the induction coil, we have a current of great quantity with little tension; and in the secondary circuit, the same converted into a current of small quantity and great tension. In Wilde's machine, again, we can, according to the kind of coils we use in the revolving armature, convert the work of the steam-engine into a strong current of little tension, or a tense current of little strength. One thing is remarkable—when a current induces another or moves another current, or induces magnetism or moves a needle, the current falls in strength so long as change is going forward; but when the change is completed—when the current has attained its final position or condition with regard to the induced circuit—when the attracting or repelling currents cease to move—when the electro-magnet is fully charged, or when the needle takes up its deflected position, the current resumes its former strength.

The Atlantic Telegraph.

The following are the details of construction of the two Atlantic cables. Fig. 149 shews the section, and fig. 150 the external appearance of the 1866 cable in their full size (1⅛ inch in diameter). The cable of 1865 is exactly the same as that of 1866, with one or two non-essential differences.

The *conductor* of both cables consists of a copper strand of seven wires, six laid round one, and weighing 300 lbs. per nautical mile, imbedded for solidity in Chatterton's compound. Gauge of single wire, ·048 of an inch; gauge of strand, ·144.

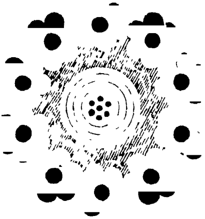


Fig. 149.

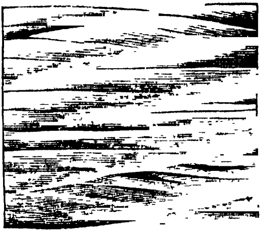


Fig. 150.

The *insulation* of both consists of four layers of gutta-percha, laid on alternately with four thin layers of Chatterton's compound. The diameter of core (conductor and insulation), ·464 of an inch.

The *external protection* of the 1865 cable consists of ten steel wires, ·095 in diameter, each wire surrounded separately with five strands of tarred Manilla hemp, and the whole laid spirally round the core, which latter is padded with tanned jute yarn. The external protection of the 1866 cable is precisely the same as this, only the wires are galvanised, and the strands of hemp are not tarred but left white.

Weight in air, 1865 – 35 cwt. 3 qrs. per nautical mile; 1866—31 cwt. per nautical mile.

Weight in water, 1865—14 cwt. per nautical mile; 1866—14¾ cwt. per nautical mile.

Each cable would bear eleven knots of itself in water without breaking.

The deepest water encountered was 2400 fathoms, and the *distance* between Valentia and Heart's Content, 1670 knots. The *length* of the cables is, 1865—1896 knots; 1866—1858 knots. The *resistances* are given by Latimer Clark as follows: the total resistance of the copper of the cable of 1865, as it lies at the bottom of the Atlantic, 7604 B.-A. units; that of

1866, 7209 B.-A. units, corresponding to 4·009 and 3·893 B.-A. units per knot respectively. In the factory the resistance of one knot of the 1866 cable at 24° C. was 4·272 B.-A. units. The total gutta-percha or insulation resistance of each cable is 2437 millions of B.-A. units per knot after one minute's electrification, and it rises to 7000 millions per knot after thirty minutes' electrification. In the factory the insulation resistance at 24° C. was 379 millions of B.-A. units per knot after one minute's electrification. The pressure and low temperature of the ocean depths have thus immensely improved the electric condition of the cables.

Leakage through the Gutta-percha.—From the above dimensions it will be seen that the gutta-percha covering is ·16 of an inch in thickness. One mile of it will offer an inner surface of about 200 square feet, so that for the first mile the current has the choice for a passage to the ground of a conductor of copper ·144 of an inch in diameter and some 1857 miles in length, or of a gutta-percha one, as it were, 200 square feet in thickness and ·16 of an inch in length. Yet such is the difference of the conducting power of copper and gutta-percha, that the resistance of the copper to the passage of the current is to that of the gutta-percha for that mile, provided it had the same qualities as the whole, roughly speaking, as 7200 to 2400 millions, or as 1 to 333,333. Each cable, when 'cut,' and charged, falls from charge to half charge in from 60 to 70 minutes; and in the time that a signal lasts, which is only a fraction of a second, not so much as ½ per cent. of the current can be led off by the total gutta-percha covering.

The Instruments.—The *battery* employed is a modification of Daniell's—12 cells are sufficient for signalling, but from 20 to 30 are generally used. The *receiving-instrument* is Thomson's Reflecting Galvanometer (157). This consists of a needle formed of a piece of watch-spring ⅜ths of an inch in length. The needle is suspended by a thread of cocoon-silk without torsion. The needle lies in the centre of an exceedingly delicate galvanometer coil. A circular mirror of silvered glass is fixed to the needle, and reflects at right angles to it in the plane of its motion. It is so curved that, when the light of a lamp is thrown through a fine slit on it, the image of the slit is reflected on a scale about 3 feet off, placed a little above the front of the flame. Deflections to the extent of half an inch along any part of the scale are sufficient for one signal. In so delicate an instrument, the sluggish swing of the needle in finally settling into any position would destroy its usefulness. To rectify this, a strong magnet, about 8 inches long, and bent concave to the instrument, is made to slide up and down a rod placed in the line of the suspending thread above the instrument. This magnet can be easily shifted as necessity may require. The oscillations of the needle due to itself are, by the aid of the strong magnet, made so sudden and short as only to broaden the spot of light. The delicacy of even this exceedingly delicate galvanometer can be immensely increased by using an astatic needle (88); each needle within a separate coil, the one lying above the other in the same plane, the current moving through each in opposite directions. The mirror is attached to the upper needle.

Varley's Condenser is intended to obviate the delay caused by induction. Fig. 151 is intended to shew its action. H is the transmitting-key. B, the sending battery; LL, the cable; G, the reflecting galvanometer; C, the condenser—alternate leaves of mica or paraffin and tinfoil (120); R, a resistance coil; P, P′, earth plates. The earth plates of the Atlantic Telegraph are really, however, strong galvanised iron cables, extending a mile or two out into the sea. H is shewn in plan, while the rest of the figure is in section. It consists of two separate keys, *a* and *b*, moving on axes (at the upper end in fig.). They are kept by springs pressing against the cross-plate, *c*, which is in connection with one of the poles (say —) of B; *a* is joined to the line, and *b* to the earth. When either key is pressed down, it falls on the plate, *d*, in connection with the other pole (+) of B. In the normal position of the key, the line is through *a*, *c*, and *b* to earth, and *d* is insulated; and it is easy to see how a + or — current is put to line, according as *a* or *b* is depressed. Let *a* be depressed, and the + pole put to line; this charges the cable and condenser, and would then cease to act if a current did not pass through R, which, however, is very slight, owing to the enormous resistance of R, a resistance immensely greater than that of the cable. The cable at the sending end is charged to a potential (page 276), corresponding to the resistance of the cable and R; the receiving end and condenser to that corresponding to R. The

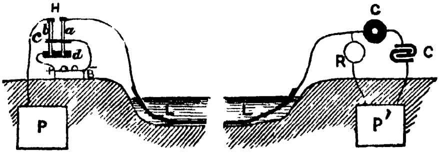


Fig 151.

charging of the condenser (whose capacity is equal to about 70 knots of the cable) is attended by a deflection of the needle of G, which ceases on the condenser being fully charged. After *a* is depressed, it is allowed to rise back on *c*, the cable is thus put to earth, its charge flows out, and its potential falls below that of the condenser, whose charge consequently flows through the galvanometer back into the cable, causing a decided opposite deflection. This forward and backward motion of the needle forms a signal. The effect of the whole is that the duration of each consecutive signal corresponds nearly to the time taken to produce it at the sending end. The reduction of the charge of the cable takes time to travel, as a wave, to the other side (from $\frac{1}{10}$th to $\frac{2}{10}$ths of a second); but the prolongation of the signal, the worst feature of embarrassment (152), is obviated; and the delay is less felt as the one cable is used to receive, the other to transmit.

The alphabet is made by opposite movements produced by one or other of the keys. The signals need not be made from zero as a starting-point. The eye can easily distinguish, at any point in the scale to which the spot of light may be deflected, the beginning and the end of a signal, and when its motion is caused by the proper action of the needle or by currents. It is thus that the mirror galvanometer is adapted to cable signalling, not only by its extreme delicacy, but also by its quickness. The deflections of the spot of light have been aptly compared to a handwriting no one letter of which is distinctly formed, but yet is quite intelligible to the practised eye. Signals in this way follow each other with wonderful rapidity. A low speed—some eight words a minute—is adopted for public messages; but when the clerks communicate with each other, as high a speed as eighteen or twenty words is attained. In fact, it is said that the only limit is the power of reading, not transmitting, signals. As it is, the speed of signalling is equal to, if not greater than, that attained on any land line of the same length, an achievement indicative of the skill and genius that have been directed to Atlantic telegraphy.

Another most important advantage derived from this method of working the cable is, that no earth-currents interfere with it. The cable and condenser being insulated, there is no voltaic circuit, no way whereby earth-currents can enter and leave the line, and any inductive effect must be of a transient character. The great resistance of the coil R renders its action with regard to earth-currents more akin to insulation than conduction. For further information, see *Good Words* (Jan. 1867), and the *North British Review* (Dec. 1866).

INDEX.

PAGE

Abel's fuses....................228
Amalgam....................77
Amalgamated zinc...........107, 124
Ampere's rule....................140
Anions and Anode....................161
Armatures.................... 7
Aureole....................191

Back-stroke.................... 84
Battery, Bunsen's....................138
———, constant....................135
———, Daniell's..........135, 213
———, electric.................... 89
———, galvanic....................131
——————, tension and quantity arrangements of— 131, 154
Battery, galvanic, tension or electromotive force of— 124, 130, 151
Battery, gas....................134
———, Grove's....................137
———, iron....................138
———, magnetic.................... 5
———, marine....................226
———, sand....................238
———, Smee's....................133
———, thermo-electric..........214
———, Wollaston's....................131
Bohnenberger's electrometer...132
Breaks.................... 185, 189, 268
Brush, electric.................... 79

Cations and Cathode....................161
Charge by cascade.................... 89
———, conductive.................... 56
———, inductive.................... 54
Circuit, closed....................111, 249
———, galvanic....................111
——————, homogeneity and polarity of....................115
Circuit, open . 111, 249

PAGE

Coercitive force.................... 7
Coil, primary....................187
———, secondary....................187
Commutators, or Rheotropes— 190, 253
Compass, mariner's.................... 23
Condenser.................... 93
————, for induction coil...190
Conducting power of metals...149
Conductor, negative.................... 77
————, prime.................... 75
Conductors and non-conductors....................49, 61, 63
Consecutive poles.................... 9
Coulomb's torsion balance...44, 73
Crown of cups, Volta's....................131
Current, chemical unit of..........145
——— electrolytic action— 161, 219
——— electro-magnetic unit of....................207
Current, galvanic..........109, 114
——————, theoretical views of origin of....................119
Current, heating effects of— 83, 100, 192, 227
———, physiological effects of..........84, 157, 192, 199
Current, strength or quantity of..........124, 126, 140, 151
Currents, action of the earth on 176
Currents, attraction and repulsion of.................... .171
Currents, derived.................... .156
————, earth.................... ...153
————, extra.................... ..119
————, induced....................186
————, sinuous.................... .180

Declination....................16, 17
———— needles or declinometers 19

PAGE
Diamagnetic bodies.............. 42
Diamagnetism.......................... 39
Dielectrics.......................... 60
Dip, magnetic.........17, 31, 34, 201
Dipping needle.................... 24
Directive action of the earth... 15
Discharge, continued.............114
———, disruptive............ 79
———, effects of.............. 63
Discharger, universal............ 91
Discharging tongs.................. 85
Diurnal variation of the needle 35
Double touch...................... 9

Electric attraction and repulsion, laws of; Electric Force....75, 271
Electric chimes.................... 83
——— clocks...................... 45
——— dance.................... 82
——— egg........................193
——— figures, Wright's........193
——— lamps......................139
——— light.......................222
——— machines.............75, 82
——— mortar.................... 91
——— pendulum................. 45
——— polarity...............48, 52
Electricity, atmospheric......... 97
——— concentrates on points........................... 70
Electricity, disguised or bound 86
———, distribution of....... 67
———, frictional .....45—106
———, of two kinds....... 45
———, sources of........... 48
———, theories of.......... 31
———, velocity of.......92, 244
Electrics and non-electrics 51
Electro-chemical order of the metals.............................122
Electrodes...... 161
Electrodynamics....................171
Electrolysis..........................161
Electro-magnetic machines.....232
——— rotations.....175
——— units..........206
Electro-magnetism................178
Electro-magnets...................181
Electro-metallurgy................219
Electrometers and electroscopes............ 71
Electro-motive force..125, 130, 151
———, chemical unit of 153

PAGE
Electro-motive force, electromagnetic unit of 210
Electromotors or rheomotors...124
Electrophorus...................... 95
Electro-plating and gilding......220
Electro-tonic state................183
Electrotype..........................219
Exploding gunpowder at a distance............................227

Galvanic pair 107
Galvanism.......... ....107—170
Galvanometers..............141, 255
Glow...........................79, 193

Inclination.......................... 17
Induction coil...............189, 265
———, current or volta-electric............ 183
Induction, magnetic.............. 6
———, magneto-electric....195
———, statical................ 51
———, Faraday's theory of........... 58
Inductive capacity.... 61
——— embarrassment.......245
Insulating stool.................. 83
Insulation.......... 50
Isoclinic lines... 31
Isodynamic lines.................. 32
Isogonic lines....................... 28

Lenz's law 151
Leyden jar.......................... 85
Lightning........................... 97
——— conductor..............102
Local action.........................124

Magnetic charts.................... 27
——— curves.................. 2
——— elements.............. 16
——— field...................... 3
——— intensity............17, 26
——— meridian 17, 30
——— moment................ 3
——— needle.................. 4
——— parallels............... 30
——— polarity................ 1
——— poles of the earth.... 29
——— sounds............182, 257
——— variations.............. 20
Magnetisation...... 8
Magnetism............ ....1—44
——— Ampere's theory of 178

PAGE
Magnetism of rotation............202
————, terrestrial........... 15
————, theories of.... 14
———————— terrestrial............ 37
Magneto-electric machine.......197
Magneto-electricity..............195
Magnetometers, Gauss's......21, 26
Magnets, action on each other 12
———, affected by heat....... 13
———, forms of................. 5
———, kinds of................. 1
———, power of............. .. 12

Ohm's Law 151

Paramagnetic bodies...........39, 42
Pile, Volta's........ 131
——, Zamboni's dry...............131
Points, effect of..................70, 83
Polarisation, galvanic............135
————, electric 52, 59, 71, 118
————, magnetic............ 6
Pole unit................... ..26, 207
Poles, galvanic.......................111
——, magnetic.......... 1
Proof-plane.......................... 42

Quantity, electric................. 64

Relay.....................................248
Resistance 124, 147, 149
———— coils....................143
————, unit of... ....150, 207
Return current.....................244

PAGE
Rheostat.............................147
Rheotome 185, 189, 268
Roberts's cartridge................227

Saturation point.................. 11
Secondary action..................163
Single touch......................... 8
Solenoids 179
Spark, electric..................79, 191
——, galvanic 101
Striking distance. 90

Telegraph, aërial line of 240
————, Bain's....................256
————, Cooke and Wheatstone's........................252
Telegraph, electric.... 234
————, Morse's....... 235
————, Steinheil's.............255
————, submarine......242, 278
Telephone..............................257
Tension, electric..............64, 124
Thermo-electric pair..............215
———— pile..............217
———— series............216
Thermo-electricity.................214
Translation...........................251

Vacuum tubes.......................193
Voltaic arc........... 224
——— electricity..........107—170
——— pair.........................107
Voltameter............................144
Wilde's magneto-electric machine 259

THE END.

Edinburgh: Printed by W. and R. Chambers.

Cheap and Comprehensive Work on Navigation,
With Illustrations, Coloured Charts of Flags of various Nations, and Signalling Flags—**Price 7s. 6d.**

NAVIGATION

BY JAMES PRYDE,
TEACHER OF MATHEMATICS, EDINBURGH.

THIS Work contains all the Problems required by the Practical Navigator, with the Rules for solving them; also the demonstrations of these Rules, together with Examples illustrative of each, and a number of Exercises to be solved by the Pupil—these Exercises being MORE NUMEROUS THAN THOSE CONTAINED IN ANY OTHER TREATISE NOW IN USE.

CONTENTS:

DECIMAL ARITHMETIC.
  Promiscuous Exercises in Decimals.
ALGEBRAIC AND ANALYTICAL SYMBOLS.
  Exercises.—Theorems on Proportion—Equidifferent and Equirational Series.—Of Logarithms.—Properties of Logarithms, and Exercises.
  CONSTRUCTION OF SCALES.
    Gunter's Scale.—On Sliding Rule.—Description and Use of Sector.
  PLANE TRIGONOMETRY.
    Of Oblique-angled Triangles.
ASTRONOMY AND GEOGRAPHY.
  Exercises.
INSTRUMENTS USED IN NAVIGATION.
  Of the Compass.—Variation of the Magnetic Needle.—On Leeway and Deviation of Compass—Exercises.
ON PLANE SAILING.
  Exercises on Plane Sailing.
TRAVERSE SAILING.
  Exercises in Traverse Sailing.
  PARALLEL SAILING.
    Exercises in Parallel Sailing.
  MIDDLE-LATITUDE SAILING.
  MERCATOR'S SAILING.
    Workman's Table for correcting Middle Latitude.—Exercises in Middle-latitude and Mercator's Sailing.
ELEMENTS OF TRIGONOMETRY CONTINUED.—Exercises
CURRENT SAILING.—Exercises.
ON PLYING TO WINDWARD.—Exercises.
  GREAT-CIRCLE SAILING.
NAUTICAL ASTRONOMY.
  Definitions, &c.—Preparatory Problems in Nautical Astronomy—To correct the Observed Altitude of Celestial Objects.—To deduce the Latitude.—Exercises in finding the Latitude.
SPHERICAL TRIGONOMETRY.
  Napier's Rules for the Circular Parts.
  Exercises on Right-angled Trigonometry.
  Oblique-angled Spherical Trigonometry.—Exercises.
  Latitude by Ex-meridian Altitudes.
  To find the Time at a Given Place.
  To find the Apparent Time and Azimuth by the Sun.—Exercises.
  Investigation of the Method of Double Altitudes.
  Finding the Latitude by Double Altitudes.—Exercises.
  Latitude and Longitude by Construction.
  Sumner's Method of Double Altitudes.
  Equation of Equal Altitudes.
  Error of Chronometer by Equal Altitudes.
  To calculate the Altitude of a Celestial Body.
  To clear the Lunar Distance.
  To find the Time and Longitude by Lunar Distance.—Exercises.
ANSWERS TO EXERCISES.
APPENDIX.
  On Weather Forecasts and Storms.
  Sextant, its Construction and Use.
  Of a Ship's Journal or Log-book.
  Commercial Code of Signals.
  Mortar and Rocket Apparatus for Saving Life.
  Regulations for preventing Collisions at Sea.—Diagrams to illustrate the use of Lights.
  Ordinary Examination Papers.
  Astronomical Tables—Description.
    N A. pp. 1 and 2 for October 1866.
    Tables of the Principal Fixed Stars.
  Commercial Chapter.
  Glossary of Nautical Terms.

Also a New Edition of MATHEMATICAL TABLES, *expressly prepared for* NAVIGATION, *Price* 3*s.* 6*d.*

W. & R. CHAMBERS, LONDON AND EDINBURGH.

In One Volume, Price 3s. 6d., with full-page Illustrations,

RAILWAYS, STEAMERS, & TELEGRAPHS.

CONTENTS.

RAILWAYS.

Roads and Vehicles before Railways.
Early Days of Railways.
Early Days of the Locomotive.
Rise of the Great Companies.
Era of the Menai Tubular Bridge.
Recent History of Railways.
Foreign and Colonial Railways.
Grand Alpine Railways: Mont Cenis.
Other Famous Railway Constructions.
Illustrations of Railway Working.
Railway Peculiarities in America.

Annals of Railways from 1815 to 1866.

STEAMERS.

Ships of Early Nations.
Voyages of Early Nations.
Rise of Steam Navigation.
Beginnings in Ocean Steaming.
Cunard Line of Atlantic Steamers.
Other Steam-routes to North America.
Ocean Steaming round the Cape.
Overland Route to the East.
West India Mail Steamers.
Central and South American Mails.
Ocean Steaming in the Pacific.
The *Great Eastern* Steam-ship.
War-ships: the Old Sailing Fleet.
War-ships: the Paddle and Screw Fleet.
War-ships: the Iron-clad Fleet.
Foreign Iron-clad Navies.
Novelties and Oddities in Ship-building.

Annals of Steamers from 1815 to 1866.

TELEGRAPHS.

The Old Modes of Telegraphing.
Adoption of Frictional Electricity.
Adoption of Voltaic Electricity.
Steps in the Progress of the System.
Chief Characteristics of Telegraphing.
New Companies and New Contrivances.
Land Telegraphs in Foreign Countries.
Ocean-cable Telegraphs.
The Atlantic Telegraph: Early Attempts.
Temporary Success in 1858.
Preparing for another Attempt: 1859—1864.
The Cable Failure of 1865.
The Cable Triumph of 1866.
Recovery of the '65 Cable.
Conclusion.

Annals of Telegraphs from 1815 to 1866.

Index.

LIST OF ILLUSTRATIONS.

Menai Tubular Bridge.
Railway over Mont Cenis.
Cannon Street Railway Station, City.
The *Great Eastern* and *Persia* under steam.
The *Great Harry*.
The *Duke of Wellington*, 131-gun Screw-steamer.
Iron-clad Turret-ship *Northumberland*.
Coiling the Atlantic Cable on board the *Great Eastern*.
The *Great Eastern* paying out the Atlantic Cable.
Telegraph Instrument-room at Foilhummerum, Valentia.

☞ *A Full Alphabetical Index affords ready means of reference.*

W. & R. CHAMBERS, LONDON AND EDINBURGH.